The International Congress for global Science and Technology

ICGST International Journal on Artificial Intelligence and Machine Learning (AIML)

Volume (14), Issue (I)
August, 2014

www.icgst.com
www.icgst-amc.com
www.icgst-ees.com

AIML Journal
ISSN Print 1687-4846
ISSN Online 1687-4854
ISSN CD-ROM 1687-4862

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ICGST International Journal on Artificial Intelligence and Machine Learning (AIML)

A publication of the International Congress for global Science and Technology - (ICGST)

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Comparison of Five Thinning Methods on the Arabic IFN/ENIT Database

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Abstract.
Thinning "Skeletonization" is a very crucial stage in the Arabic Character Recognition (ACR) system. It simplifies the text shape and reduces the amount of data that needs to be handled and it is usually used as a pre-processing stage for recognition and storage systems. The skeleton of Arabic text can be used for: baseline detection, character segmentation, and features extraction, and ultimately supporting the classification. In this paper, five of the state of the art thinning algorithms are selected and implemented. The five algorithms are: SPTA, Zhang-Suen parallel thinning algorithm, Voronoi- based thinning algorithm, thinning and skeletonization based morphological operation algorithms. The five selected algorithms are applied on the IFN/ENIT dataset. The results obtained by the five methods are discussed and analyzed against the IFN/ENIT dataset based on preserving shape and the text connectivity, preventing spurious tails, maintaining one pixel width skeleton and avoiding the necking problem as well as running time efficiently. In addition to that some performance measurement for checking text connectivity, spurious tails and calculating the stroke thickness are proposed and carried out.

Keywords: *Thinning, Skeleton, Arabic Character Recognition, SPTA, Zhang-Suen,* Voronoi-based, *morphological, Text connectivity.*

1. Introduction

In Image processing, the extraction of the skeleton of digital images is widely used as a pre-processing stage for recognition and storage systems. Skeleton of characters is the single pixel wide set of it. The main aim of the thinning process is to reduce the outline of a character in which the several-pixel character thickness is reduced in the process of thinning into a single pixel shape that forms the basis of the character. It eliminates a lot of unwanted information, and hence reduces the memory required for storing the structural information. The skeleton products usually construct from a set of lines, curves, and loops [1][12] [3].

Generally, thinning methods can be broadly classified into two, iterative and non-iterative [10]. In an iterative method the pixels which can be removed, pertaining to a condition that they satisfy specific conditions imposed by the algorithm, are flagged during each iteration. The pixels that are flagged are a function of the previous iteration resultant image and current iteration processed image. The process is continued until no further pixels in the image are flagged. The order of traversal of pixels in the image may be sequential [14] or parallel [16]. The basic feature exploited during the processing is the pixel neighbourhood (generally the 8 pixels surrounding the main pixel in a 3 x 3 window). The process of flagging and removing of pixels in repetitive iteration following a specific traversing order are sequential methods while in a parallel method flagging and removing a pixel is considered a function of the previous iteration output image. A non-iterative method on the other hand, is one where the flagging of pixels is carried on if they satisfy special properties or parts of the polygon regions where a region is divided into set of regular or irregular polygons [12]. Non-iterative methods have an advantage that they produce accurate results but are at the cost of computation time [1].

Thinning is used in many recognition applications such as, text, chromosome, and finger print analysis [3] [12] [10]. It is very important in Arabic Character Recognition (ACR) system, it simplifies the Arabic texts shapes for segmentation process, feature extraction, and classification, and this is resulted in reducing the amount of data that need to be handled [2]. Many ACR systems have been developed based on the text skeleton. The skeleton was extensively used in supporting each of feature extraction and classification stages [7]. Beside that its used as the basis for many methods designed for Arabic text segmentation, more details about the segmentation methods based on text skeleton can be found in [4].

The skeleton was also used in the estimation of the Arabic handwriting word baseline [1].

Over the years, few thinning algorithms specially developed for the Arabic text. Several thinning algorithms, which are designed for different purposes, have been used to extract the skeleton of Arabic text. Mostafa [11] used the non-iterative thinning algorithm, which was developed by Kegl and Krzyzak [6], to segment the Arabic cursive printed words into characters or into small primitives. In addition, Benouareth et al [5] used the sequential thinning algorithm created by Pavlidis [15] for Arabic handwritten word recognition using Hidden Markov Models with explicit state duration. Many other thinning algorithms have been used to extract the skeleton of Arabic text, such as [1] [8] [16].

In the literature, there were many thinning algorithms have been proposed for different purposes, and a comprehensive survey of these methods is contained in [10]. Generally, in the thinning algorithm research, there exist two main problems where the actual study focuses, namely, the algorithm execution time and the resulting thinned image shape. The thinning algorithms produced may also generate good skeletons for some shapes but can produce poor skeletons for others. It is very difficult to develop a generalized thinning algorithm which can produce satisfactory results for all varieties of pattern shapes [1].

An effective thinning algorithm for Arabic text should ideally meet the following requirements: preserving shape and text connectivity, preventing spurious tails, maintaining one pixel width skeleton, avoiding necking problem, and running time efficiently. Failing to do so, results in the words to be disconnected into subwords. Hence, it completely damages and changes the text features, while affecting the shape of text [1]. Safe Point Thinning Algorithm (SPTA), Zhang-Suen thinning algorithm, Voronoi-based thinning algorithm, thinning and skeletonization based morphological operation methods (TBMO, SBMO) are selected to show the impact of the thinning on the ACR.

This paper is organized as follows. Section (2) provides and describes the five selected thinning algorithms. Section (3) presents the experimental results. Section (4) discuses the results based on the challenges of thinning Arabic text. Section (5) summaries the obtained results. Finally, section (6) presents the conclusion and the future direction.

2. The Thinning Algorithms

A. *Safe Point Thinning Algorithm (SPTA)*

SPTA is a sequential iterative algorithm proposed by Naccache and Shinghal [14]. In which edge points are deleted while endpoints, and connectednesses are preserved and excessive erosion is avoided. Edge points are the pixels on the edges of a shape and end points are pixels at the end of a stroke. The input image is considered to have shape pixels in black and background pixels as white pixels. For a pixel with coordinate (x, y), the pixels (x+1, y), (x-1, y), (x, y-1) and (x, y+1) constitute the 4-neighbor set, and the 8 pixels in the 3 x 3 window around the pixel (x, y) are the 8 neighbor, (Figure 1) [1].

t_5	t_6	t_7
t_4	P	t_0
t_3	t_2	t_1

Figure 1. A point p and its 8-neighbors (t0 to t7). The points t0, t2, t4 and t6 are referred to as the 4-neighbors of p

An edge point is a black pixel with at least one white 4-neighbour while an end point is a black pixel with at least one black 8-neighbor and break point is a pixel whose removal will break the connectedness of the pattern. The edge points pixels are flagged if they are not end points or do not break connectedness or do not cause excessive erosion. At the end of each iteration all the flagged pixels are removed. If no flagged pixels are present, it is the end of the process. The edge point is called as left-edge point if t4 is white, right-edge point if t0 is white, top-edge point if t2 is white and bottom-edge point if t6 is white [1].

A Boolean equation is framed for identifying an edge point without deleting end point and breaking excessive erosion and also without breaking connectedness, taking into consideration the 8-neighbors of a pixel.

For identifying a left-edge point the Boolean expression is

$$S_4 = t_0.\ (t_1 + t_2 + t_6 + t_7).\ (t_2 + \sim t_3).\ (t_6 + \sim t_5) \qquad (1)$$

Similarly, right edge point, top edge point, bottom edge point are identified using the Boolean expressions for S0, S2 and S6 respectively.

$$S_0 = t_4.\ (t_2 + t_3 + t_6 + t_5).\ (t_6 + \sim t_7).\ (t_2 + \sim t_1) \qquad (2)$$

$$S_2 = t_6.\ (t_7 + t_0 + t_4 + t_5).\ (t_0 + \sim t_1).\ (t_4 + \sim t_3) \qquad (3)$$

$$S_6 = t_2.\ (t_3 + t_4 + t_0 + t_1).\ (t_4 + \sim t_5).\ (t_0 + \sim t_7) \qquad (4)$$

SPTA is a two stage process. During the first stage the edge pixels are identified using the Boolean expressions S0, S2, S4, S6 and are flagged. During the second stage the flagged pixels are removed resulting in the thinned image [1].

Algorithm (1) illustrates the SPTA algorithm.

Algorithm (1): SPTA
Input: binary text image
Output: thinned image

Begin
  scan the image row by row
    for each pixel p (x, y) apply the 8-nighbour (see Fig1)

let t_0, t_1, t_2, t_3, t_4, t_5, t_6, t_7 = values of (x+1, y),(x+1, y+1), (x-1, y), (x-1, y-1), (x, y-1), (x+1, y-1), (x, y+1), and (x-1, y+1)) respectively.
examine (p)
if one of the following conditions is true (true means it is not end or break points)

$S_4 = t_0.\ (t_1 + t_2 + t_6 + t_7).\ (t_2 + \sim t_3).\ (t_6 + \sim t_5)$ (1)
$S_0 = t_4.\ (t_2 + t_3 + t_6 + t_5).\ (t_6 + \sim t_7).\ (t_2 + \sim t_1)$ (2)
$S_2 = t_6.\ (t_7 + t_0 + t_4 + t_5).\ (t_0 + \sim t_1).\ (t_4 + \sim t_3)$ (3)
$S_6 = t_2.\ (t_3 + t_4 + t0 + t_1).\ (t_4 + \sim t_5).\ (t_0 + \sim t_7)$ (4)

Remove the pixel
end

B. *Zhang-Suen Parallel Thinning Algorithm*

Zhang and Suen [16] parallel thinning method is considered as the benchmark for most of the thinning methods developed. Generally it is considered to be fast enough as well as accurate in thinning different patterns. The speed is because it is a parallel algorithm meaning the new pixel value is a function of only previous iteration resultant image. The algorithm is a two tier one where in during the first tier pixels are flagged pertaining to a given set of conditions. If no pixels are flagged during the first tier the process stops. If nonzero numbers of pixels are flagged they are removed and the second tier iteration starts. The pixels are flagged if they satisfy the following conditions [1]:

i. If the number of transitions from background to foreground which means from back to white in the pixel neighborhood is one.
ii. If the number of black neighbors is between two and six in the 3 x 3 pixel neighborhood.
iii. Either t0 or t2 or t4 is white.
iv. Either t0 or t2 or t6 is white.

Zhang-Suen parallel thinning algorithm is selected to thin the Arabic cursive text using the following algorithm (see algorithm 2).

Algorithm (2): Zhang-Suen parallel thinning algorithm
Input: binary text image
Output: thinned image.

Begin
scan the image row by row
for each pixel p (x, y) apply the 8-nighbour (Fig 1)
let t_0, t_1, t_2, t_3, t_4, t_5, t_6, t_7 = values of (x+1, y),(x+1, y+1), (x-1, y), (x-1, y-1), (x, y-1), (x+1, y-1), (x, y+1), and (x-1, y+1)) respectively.

let A(P) be the number of zero patterns in the order set $t_0 \ldots t_7$
let B(P) be the number of non-zero neighbors of P

start sub-iteration 1:
delete P if the following conditions are satisfied:
a) $2 \le B(P) \le 6$
b) $A(P) = 1$
c) $t_0 * t_2 * t_6 = 1$
d) $t_0 * t_4 * t_6 = 1$
end sub-iteration 1
start sub-iteration 2
delete P if the following conditions are also satisfied:
a) and b) from above
c') $t_0 * t_4 * t_6 = 1$
d') $t_2 * t_4 * t_6 = 1$
end sub-iteration 2
End

C. *Voronoi- based thinning Algorithm*

Voronoi Diagrams (VDs) is defined as a rediscovered mathematical concept from the 19th century. It is one of the most fundamental and useful construction defined by irregular lattices. Voronoi vertex, edges, area neighbors are considered as properties and terms that associated with VDs [9].

Voronoi- based thinning Method is a novel non-iterative thinning approach proposed by Al-Shatnawi [9] for skeletonization the Arabic handwritten text. The Voronoi- based thinning method extracts the skeleton of handwritten text based on the selected sampling along the text contour. Then, the Point-VD is constructed from these selected sampling points. Only the VD vertices which are located within the text boundaries are kept and joined. Sampling interval (R) is significant for this performance, Using the sampling interval R=5 is the best as proven by Al-Shatnawi [9]. Algorithm (3) illustrates The Voronoi-based thinning Algorithm. Figure 2 presents the thinning process for the handwriting sentence 'Thiraa bin Ziad' (ذراع بن زياد) using the Voronoi- based thinning Method.

Algorithm (3): Voronoi- based thinning algorithm
Input: binary text image [9]
Output: thinned image

Begin
every pixel in the image is labelled with a number referring to the connected component it belongs to,
pixels of the foreground are labelled with 1
trace the inner and outer contours
select samples along the contour using fixed sampling interval R=5.
construct VDs using all samples as generators
keep the VDs vertices which are located within the text boundaries and delete all others VD components.
if two vertices have two or more determined VD cells they are adjacent vertices
join each vertex with its adjacent vertices

End

D. *Thinning And Skeletonization Based Morphological Operation Methods*

The TBMO method is selected to thin the Arabic cursive text using the following algorithm (see algorithm 4) [1][9].

Algorithm (algorithm 4): TBMO algorithm
Input: binary text image
Output: thinned image

Begin
 scan the image row by row
 for each pixel (p (x, y)) apply the 8-nighbour (Figure 1)
 let $t_0, t_1, t_2, t_3, t_4, t_5, t_6, t_7$ = values of $(x+1, y)$,$(x+1, y+1)$, $(x-1, y)$, $(x-1, y-1)$, $(x, y-1)$, $(x+1, y-1)$, $(x, y+1)$, and $(x-1, y+1)$) respectively.
 let A(P) be the number of non-zero neighbors of P
 let B(P) be the number of 0 to 1 (or 1 to 0) transitions in the sequence ($t0$ to $t7$)
 start sub-iteration 1:
  mark any edge pixel P=1 not satisfying at least one of the following conditions (to be deleted in second step):
   A(P) = 0 (an isolated point)
   A(P) = 1 (tip of a line)
   A(P) = 7 (located in concavity)
   A(P) = 8 (not a boundary point)
   B(P) >= 2 (on a bridge connecting two or more edge pieces)
 end sub-iteration 1
 start sub-iteration 2:
  deleted all marked edge points
end

The SBMO method extracts the skeleton of the text image by calculating the distance transform of the image. The method is selected to thin the Arabic cursive text using the following algorithm (see algorithm 5).

Algorithm (5): SBMO algorithm
Input: binary text image
Output: thinned image

---

begin
 start iteration 1;
  let $k = 0$; k is an initial value.
  scan the image row by row
   examine each pixel
    if pixel (x, y) is inside the shape
     $I_k(x, y) = 1$
    else
     $I_k(x, y) = 0$
 end iteration 1
 start iteration 2;

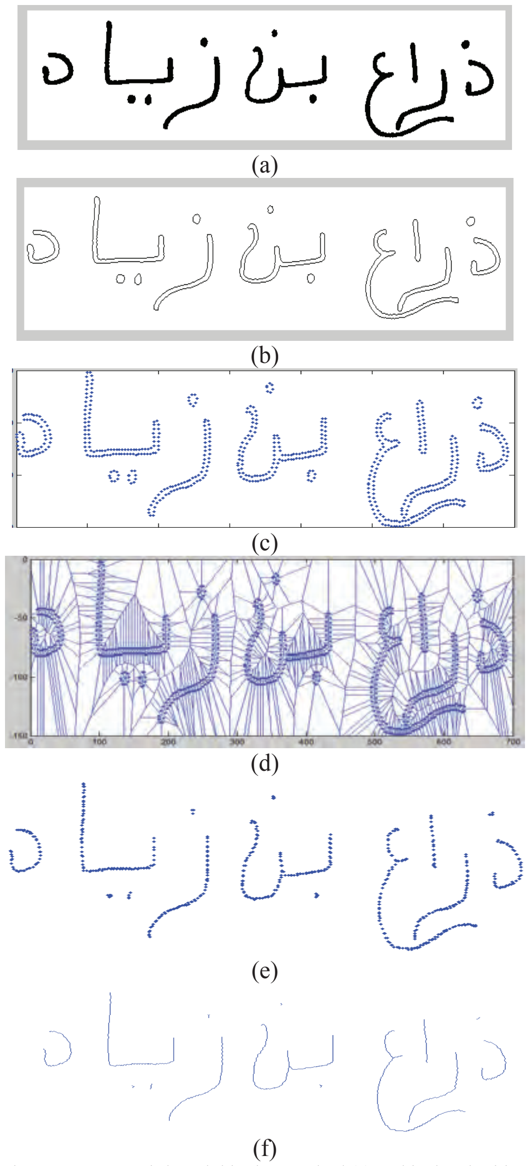


Figure 2. Voronoi- based thinning Method (a)Arabic handwriting sentence ‘Thiraa bin Ziad’ (ذراع بن زياد) (b) Edge detection and contour tracing (c) Sampling process (d) VD constructed (e) Voronoi vertices inside the text boundaries (f) Skeleton.

---

  repeat the following until no more change can be made
   $K = k+1$
   for all I_k-1 $(x, y) = k$, do $I_k(x, y) = \min \{ I_k\text{-}1\ (i, j)\}+1$; (i, j) is the four closet neighbour of (x, y)
 end iteration 2;
 start iteration 3:
  the skeleton is the set of points given below
   $\{(x, y) / I_k(x, y) = \max \{ I_k(i, j) \} \}$
 end iteration 3;
end

---

3. Experimental Results

The SPTA, Zhang-Suen, Voronoi-based, TBMO and SBMO thinning algorithms have been implemented using matlab® programming language on duo core 2.0 GHZ in 2011. The five methods are applied on the demo version of the IFN/ENIT handwritten dataset [13]. Figure 3 shows examples of the thinned images obtained using the five methods implemented in this paper.

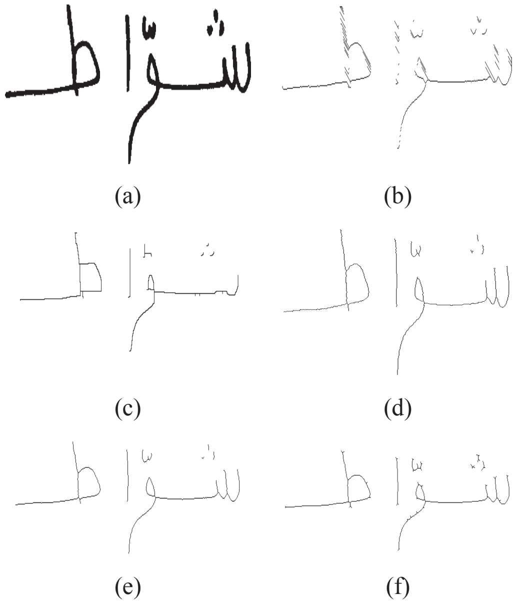


Figure 3. Thinned images produced by (a) original (b) SPTA (c) Zhang Suen (d) Voronoi- based (e) TBMO, and (f) SBMO.

4. Discussion

An effective thinning algorithm for Arabic text should ideally meet the following requirements: preserving shape and text connectivity, preventing spurious tails, maintaining one pixel width skeleton, avoiding necking problem and running time efficiently. The results obtained by the five methods were compared against the IFN/ENIT dataset based on the following criteria:

A- Preserving the Text Connectivity

Preserving the text connectivity is the most important aspect in any thinning method. Preserving the text connectivity can be examined through a comparison of the number of connected components in both the thinned image and the original one. If the numbers of connected components are equal in both images, the method maintains the text connectivity. Otherwise it does not maintain. The following algorithm is proposed to verify the effectiveness of preserving the text connectivity for any Arabic thinning algorithm (see algorithm 6) [1][9].

Algorithm (6): Checking preservation text connectivity
Input: original and thinned images
Output: preserve the text connectivity or does not preserve the text connectivity

```
begin
    read the original image.
    scan the image row by row.
    find the connected component by using the 8-
    neighborhood representation.
    count the number of the connected components
    of the original image.
    read the thinned image.
    scan the image row by row
    find the connected component by using the 8-
    neighborhood representation.
    count the number of the connected
    components of the thinned image .
    examine between the number of the connected
    components in the original and the   thinned
    images
        if they are equal
    return the thinning method preserve the text
    connectivity
        else  return it does not preserve the text
    connectivity
end
```

Figure 4 shows the connected components and their numbers for the thinned images of Figure 3. As shown in Figure 4, Zhang-Suen method, Voronoi-based method, TBMO and SBMO methods generated skeletons that preserve the connectivity, because they have the same number of connected components in the original image. However, SPTA did not do so.

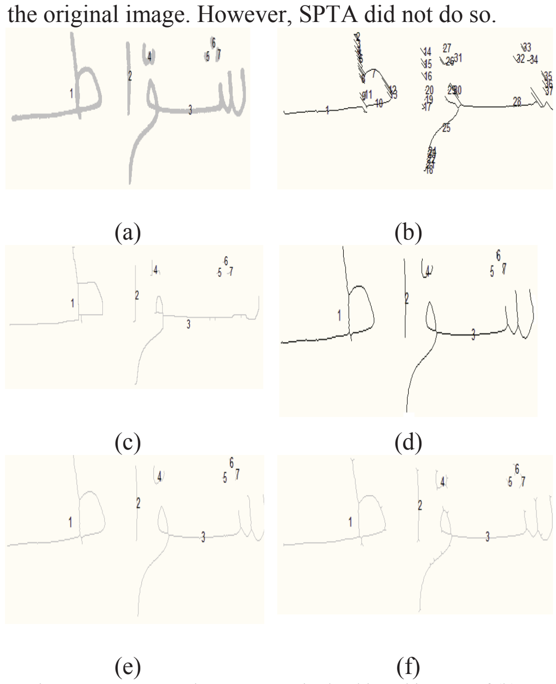


Figure 4. Connected components in the thinned images of (b) SPTA (c) Zhang-Suen (d) Voronoi-based (e) SBMO, and (f) TBMO methods

The text connectivity check algorithm is implemented on the thinned images, produced by the five algorithms, on the IFN/ENIT dataset. The numbers of the skeletons preserved text connectivity are listed in the Table 1. Furthermore the performance is calculated and listed by the ratio between the numbers of images preserved text connectivity and 569 which is the number of images used in the testing.

Table 1 Results of checking the text connectivity preservation of the output images of the five selected thinning methods

The thinning method	Number of skeletons that have preserved the text connectivity out of 569	The Performance %
SPTA	0	0.0%
Zhang-Suen	513	90.16%
Voronoi-based	569	100.0%
SBMO	569	100.0%
TBMO	569	100.0%

Figure 5 shows the performance of preserving the text connectivity for the five thinning methods, for the IFN/ENIT dataset.

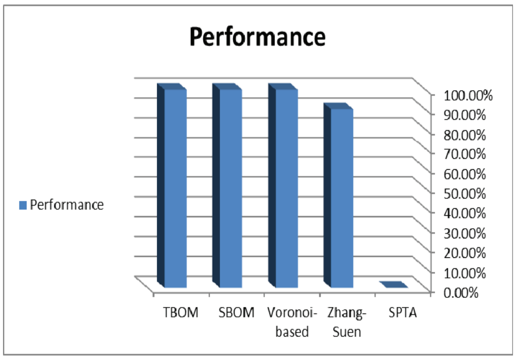


Figure 5. The performance of preserving the text connectivity for the five thinning methods for the IFN/ENIT handwritten dataset

Based on Figure 5, Voronoi-based, TBMO and SBMO methods generated skeleton that preserves the connectivity for the entire IFN/ENIT handwritten dataset. Zhang-Suen algorithm preserved the connectivity for 513 images out of the 569 images of the IFN/ENIT handwritten dataset. It does not do all, because it deletes 2 x 2 window which leads to disconnectivity in some places, specially in the junction. While SPTA did not do so. Therefore, SPTA will not be used in the other comparisons.

B- Producing One Pixel Width Skeleton

In this section, an experiment is carried out to verify that the methods implemented in this work produced skeletons of one unit pixel width. The stroke thickness is measured by the following algorithm which first proposed by Hew and Alder (see algorithm 7) [9].

Algorithm (7): Estimate Thickness (O: is an object in an image)
Input: binary text image
Output: number of pixels

Begin
  scan the image row by row
  calculate the area of object O, A(O)
  calculate the perimeter length of the object O, L(O) using 8-neighbouring method
  calculate the stroke thickness T:
  if $L > 2 \times A$ then $T = (A / (L/2))$
  else $T = \text{round}(A/L)$
end

The proposed stroke thickness estimation algorithm is implemented on the produced skeletons by the four thinning methods (i.e. the five selected thinning algorithms except SPTA), for the IFN/ENIT dataset. The numbers of the produced skeletons which have one pixel width are listed in the Table 2. Furthermore the performance is calculated and listed by the ratio between the number of images produced one pixel width skeleton and 569 which is the number of images used in the testing.

Table 2 Results of one unit pixel width skeleton on the resulted images of the four selected thinning algorithms.

The thinning method	Numbers of skeleton have one pixel width out of 569 thinned images	The Performance %
Zhang-Suen	413	72.58%
Voronoi-based	569	100.0%
SBMO	569	100.0%
TBMO	487	85.59%

The performance of one unit pixel width for the four selected thinning algorithms is shown in Figure 6.

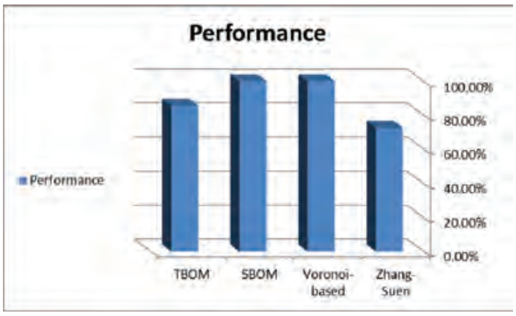


Figure 6. The performance of one unit pixel width for the four selected thinning algorithms.

Based on Figure 6, the Voronoi-based, SBMO methods generated skeleton that has one pixel width, for the IFN/ENIT handwritten dataset. The Zhang-Suen and TBMO methods did not do so, because they produce a lot of spurious tails which will be shown in the next section.

C- Producing Spurious Tails

In this section, a new experiment is carried out to measure the effectiveness of producing spurious tails on the four selected thinning algorithms. Spurious tails are considered as one of the most common problems of text thinning. Generally, these spurious tails are usually perpendicular to the thinned text. Spurious tails usually are perpendicular to the text form a T-junction and are distinct from strokes. These are like short terminals not exceeding the thickness of the text. The following algorithm is proposed for finding the spurious tails (see algorithm 8) [9].

Algorithm (8): Checking the Spurious Tails
Input: text thinned images, and text original image
Output: the algorithm produces spurious or it does not produce spurious.

```
begin
read the original image
   calculate the thickness of character using algorithm 7.
   read the thinned image
   for each connected component do the following
   apply the 8-nighbourhood chain code representation
   if there is change in the movement direction
        start counting the number of pixels
        if it is terminated and the number of pixels less than the thickness of character
           return the thinning algorithm produces spurious tails
       else return it does not produce spurious tails
end
```

The effectiveness is measured using the proposed checking spurious algorithm by the number of thinned images produced those spurious tails. The numbers of the skeletons which have produced spurious tails are listed in Table 3. Furthermore the performance is calculated by inverting the ratio between the number of images produced spurious tails and the total number of images used in the test (i. e 569).

Table 3 Results of checking spurious tails of skeletons on the resulted images of the four selected thinning algorithms.

The thinning method	Numbers of skeleton have produced spurious	The Performance %
Zhang-Suen	569	0.0%
Voronoi-based	6	98.95%
SBMO	23	95.95%
TBMO	569	0.0%

Figure 7 shows the effect of producing spurious tails on the selected four thinning algorithms.

Figure 8 show examples of spurious tails produced by the Zhang-Suen, Voronoi-based, SBMO and TBMO methods.

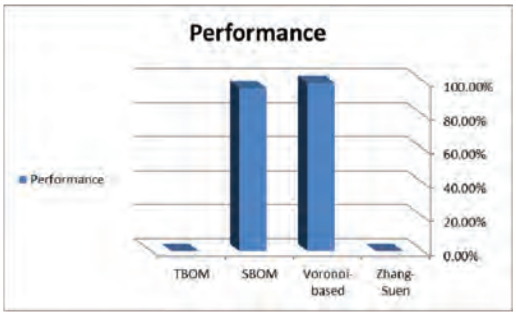
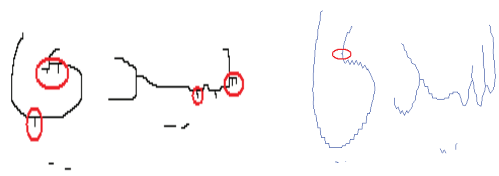


Figure 7. The effect of producing spurious tails on the four selected thinning methods.



(a) (b)

(c) (d)

Figure 8. Example of spurious tails produced by (a) the Zhang-Suen (b) Voronoi-based (c) TBMO and (d) SBMO.

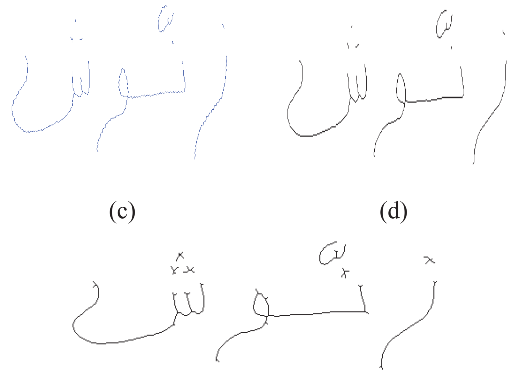
Based on Table 3, Voronoi-based thinning algorithm, SBMO are appropriate and effective as they generate less spurious tails. While Zhang-Suen and TBMO methods did not do so.

D- Shape Information

The Arabic text thinning algorithm must be able to deal with various shapes or structure in the text images such as curves, arcs, junctions, elongated, loops, and lines. To illustrate the impact of the fourth selected methods on shape information preservation of the Arabic text, the Arabic handwritten word 'Zanoush' (زنوش) has been chosen. The image was chosen because it consists of various shapes, including dots, junctions, arcs, zigzag and loops. The skeletons obtained by the four methods of the word 'Zanoush' (زنوش) are shown in the Figure 9.

Based on Figure 9, the Voronoi-based, SBMO and TBMO methods can deal with various shapes and structures in the characters images such as curves, junctions, arcs, loops, elongated and line. Generally, the skeletons produced by the three methods preserve the topology of the images as the images may have slightly small changes in the shape. But the most important fact is that the three thinning algorithms still preserves the abstraction of the image patterns although the size of the objects may change. This fact has to be taken into consideration as the thinning algorithm is applied for handwritten text and the skeletons produced can be applied in character recognition system. However, the four thinning algorithms did not preserve the geometric aspect of the images.
On the other hand, it is clear that in the Figure 9, Zhang-Suen thinning algorithm did not preserve the topology of the images. It made big changes on the text features, especially at the terminals [9].

(a) (b)



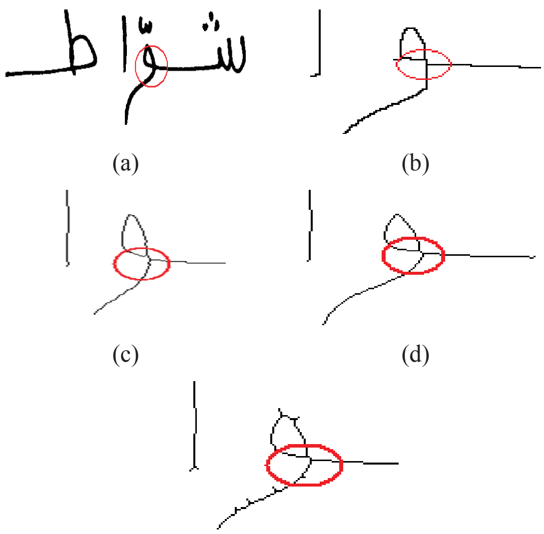
(c) (d)

(e)

Figure 9. Arabic handwritten word 'zanoush' (زنوش) thinned by (b) Zhang-Suen (c) Voronoi-based (d) SBMO and (e) TBMO methods.

E- Necking Problem

Necking problem arise when two strokes cross each other as the shape of the letter X in English [13], thinning at cross over points is one of the main challenges in the thinning process and the points of the intersection can be maintained at the crossover point. From the word shown in the Figure 3, the character Waw 'و', which is located in the middle of the word, is enlarged in Figure 10 to illustrate the efficiency of the four selected algorithms in thinning characters necking. As shown in Figure 10, all methods were not perfect in thinning the intersection [9].



(a) (b) (c) (d) (e)

Figure 10. Necking problem produced by (b) Zhang-Suen (c) Voronoi-based (d) SBMO, and (e) TBMO methods.

F- Speed

The processing time for the five methods is calculated in seconds based on the CPU time obtained during the

program execution. Table 4 shows the overall average processing time taken by the five thinning methods in thinning the 569 images of IFN/ENIT handwritten dataset.

Table 4. The overall average processing time taken by the five selected thinning methods

	SPTA	Zhang-Suen	Voronoi-based	SMOM	TMOM
Total time (sec)	7.2662	5.0867	95.1059	15.7230	9.8267

Based on the Table 4, among the five methods, Zhang-Suen thinning algorithm is the fastest thinning method, while Voronoi-based thinning method is the slowest one.

5. SUMMARY OF THE RESULTS

Table 5 summarizes the results of the comparison done between the SPTA, Zhang-Suen, Voronoi-based, SBMO and TBMO methods.

	SPTA	Zhang-Suen	Voronoi-based	SMOM	TMOM
Preserving Connectivity	Does not	Preserves	Preserves	Preserves	Preserves
Producing One-pixel width	No	No	Yes	Yes sometimes no	Yes
Preserving Shape Information	No	Yes	Yes	Yes	Yes
Preserving Dots	No	No	Yes	Yes	Yes
Preventing Spurious tails	No	No	Yes	No	Yes
Avoiding Necking Problem	No	No	No	No	No
Geometric Preserving	No	No	No	No	No
Processing Time	Faster	Fastest	Slowest	Faster	Fast

Table 6 shows the performance of the five selected methods, for IFN/ENIT handwritten dataset, calculated based on effectiveness of the methods in preserving shape and text connectivity, producing skeleton of one pixel unit width, and producing spurious tails.

Table 6. The performance of the five selected methods on the IFN/ENIT dataset.

	Preserving text connectivity and shape	One pixel unit width	Producing spurious tails	The performance
SPTA	0.0%	0.0%	0.0%	0.0%
Zhang-Suen	100.0%	72.58%	0.0%	57.53%
Voronoi-based	100.0%	100.0%	98.95%	99.65%
SMOM	100.0%	100.0%	95.95%	98.65%
TMOM	100.0%	85.59%	0.0%	61.86%

Figure 11 shows the performance of the five selected methods on the IFN/ENIT handwritten dataset in a chart.

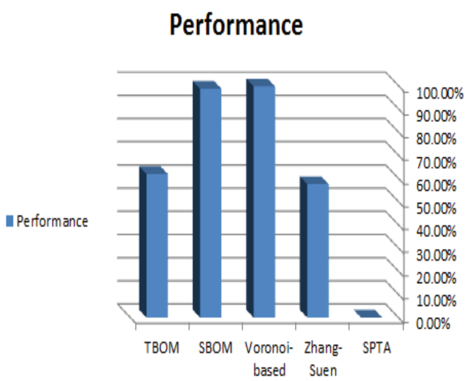


Figure 11. The performance of the five selected methods on the IFN/ENIT handwritten dataset.

Based on Table 6, the Voronoi-based method produced the best skeleton compared with the other four selected thinning methods. It produced about 99.65% acceptable skeletons that preserve shape and connectivity and moreover does not produce spurious tails and have one-pixel width, on the IFN/ENIT dataset.

6. Conclusion and Future Direction

In this paper, five of the state of the art thinning algorithms were selected and implemented. The five algorithms including: SPTA, Zhang-Suen thinning algorithm; Voronoi-based thinning algorithm, Thinning and Skeletonization based morphological operation methods. The five selected algorithms were applied on the IFN/ENIT dataset. The results obtained by the five methods were discussed and analyzed against the IFN/ENIT dataset based on the following

criteria: preserving shape and the text connectivity, preventing spurious tails, maintaining one pixel width skeleton and avoiding the necking problem as well as running time efficiently. As well as some performance measurement for checking text connectivity, spurious tails and calculating the stroke thickness were proposed and carried out.

The Voronoi-based thinning algorithm produced the best skeleton compared with the SPTA, Zhang-Suen, Thinning and Skeletonization based morphological operation methods. It produced about 99.65% acceptable skeletons that preserve shape and connectivity and moreover does not produce spurious tails and have one-pixel width, for the IFN/ENIT dataset. On other hand, the others selected methods produced about 0.0%, 57.53%, 98.65%, 61.86%, respectively acceptable skeletons for the same data set. Zhang-Suen thinning algorithm is the fastest among the five selected algorithms, but it does not preserve the shape information and produce spurious tails. SPTA failed in all measurement. It cannot be used to thin the Arabic text. Voronoi-based and Skeletonization based morphological operation thinning methods are appropriate and effective in thinning the Arabic text. Thinning based morphological operation method preserves the shape information, but it produces a lot of spurious tails. On other hand, the five selected methods suffer from some necking problems on certain characters such as Waw (و) and Meem (م).

In the future, it would be interesting to use the criteria that have been proposed in this paper, to measure the effectiveness of the thinning methods that have been used in the development the segmentation and baseline detection of Arabic text, and improve these methods using robust Arabic thinning algorithm.

7. References

[1] A. Al-Shatnawi, K. Omar, B. AlFawwaz and A. M Zeki. Skeleton extraction: Comparison of five methods on the Arabic IFN/ENIT database. 6th International Conference on Computer Science and Information Technology (CSIT), pp.50- 59, 26-27 March, 2014.

[2] A. AL-Shatnawi, F. AL-Zawaideh. S. AL-Salaimeh and K. Omar. Offline Arabic Text Recognition System – An Overview. World of Computer Science and Information Technology Journal (WCSIT). Vol. 1, No. 5, pp 184-192, 2011.

[3] A. AL-Shatnawi, K. Omar. and A. M. Zeki. Challenges in Thinning of Arabic Text.. ICGST International Conference on Artificial Intelligence and Machine Learning (AIML-11), Dubai. United Arab Emiratis. pp 127-133. 12-14 April. 2011.

[4] A. M. Zeki. The Segmentation Problem On Arabic Character Recognition – The State Of The Art. 1st International Conference on Information and Communication Technology (ICICT). pp. 11-26. 2005.. Karachi, Pakistan.

[5] A. Benouareth, A. Ennaji and M. Sellami. Arabic handwritten word recognition using HMMs with explicit state duration. EURASIP Journal on Advances in Signal Processing. 2008 (1-13).

[6] B. Kegl and A. Krzyzak. Piecewise linear skeletonization using principal curves. IEEE Transactions on Pattern Analysis and Machine Intelligence 24, N 1, pp. 59-74, 2002.

[7] J. Cowell and F. Hussain. Thinning Arabic characters for feature extraction. IEEE Conference on Information Visualization. London, UK. pp. 181-185. 25-27 July. 2001.

[8] J. Hilditch. Comparison of thinning algorithms on a parallel processor. Image Vision Computing, 1, 115–132. 1983.

[9] A. AL-Shatnawi. "A Non-Iterative Thinning Method Based on Exploited Vertices of Voronoi Diagrams," PhD thesis, University Kebangsaan Malaysia, Malysia, 2010.

[10] L. Lam, S-W. Lee, and C.Y. Suen,. Thinning methodologies, a comprehensive survey. IEEE Transactions on Pattern Analysis and Machine Intelligence. 14(9): 869-885. 1992.

[11] M. G. Mostafa. An adaptive algorithm for the automatic segmentation of printed Arabic text. 17th National Computer Conference. pp. 437-444. Madinah, Saudi Arabia. 5-8 April. 2004.

[12] M. Melhi. S. Ipson. and W. Booth. A novel triangulation procedure for thinning hand-written text, Pattern Recognition Letters, (22)1059–1071. 2001.

[13] M. Pechwitz, S. S. Maddouri, V. Märgner, N. Ellouze, and H. Amiri,. IFN/ENIT- Database of Handwritten Arabic Words. Colloque International Francophone sur l'Écrit et le Document (CIFED'02). pp. 129-136. Hammamet, Tunisia. 21- 23 October. 2002.

[14] N. J. Naccache and R. Shinghal. SPTA: A Proposed Algorithm for Digital Pictures. IEEE Trans. on Systems, Man and Cybernetics, vol. SMC-14(3) 409-418. 1984.

[15] T. Pavlidis. Algorithms for Graphic and Image Processing, Computer science press, Rockville, Md, USA, 1982.

[16] T. Y. Zhang. and C. Y. Suen. A Fast Parallel Algorithm for Thinning Digital Patterns. Comm. ACM, vol. 27(3) 236-239. 1984.

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Converting UML Class Diagram with Anti-Pattern Problems into verified Code relying on Event-B

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Abstract
In the sequential steps to generate the verification code, there are many barriers. Recently, research started to propose solutions for some of them. This paper discusses all the steps briefly. This paper will explore the area of bad practices, namely anti-patterns, and their consequences in UML class diagram. The proposal depends on using the integration between event-B as a formal method and Pattern language. It is a new methodology to detect anti-patterns. The proposal also integrates requirements, codes and verification in system development life cycle. Satisfiability Modulo Theory (SMT) solver is suggested to enhance the proposed approach. The benefits of using the proposal are increasing the automation degree, reducing the proof effort, detection of model anti-patterns, generating high quality code and reusability. This is specially to generate the verified code from UML class diagram model. A case study of an auto teller machine (ATM) model is presented to demonstrate the proposed methodology.

Keywords: *Formal method, Event-B, Pattern, Anti-pattern, SMT (Satisfiability Modulo Theory), Code generation, RSM (Resource Standard Metrics), ATM(auto teller machine).*

1. Introduction
Event-B is a system modeling language in a closed system. It is the extension of the B-method for specification, refinement and verification for complex systems [1]. Nowadays, there are many tools to generate programming language code to UML model as "Altova UModel" [2]. But our scoping in this paper is a guarantee to avoid not only syntax error but also the anti-patterns problems, and it's also guarantee for high quality code. There are many classifications for UML anti-patterns as in reference [3], [4] and [5]. The proposed approach in this paper uses the following: Pattern language, Proof obligation as a criterion, SMT solver as a prover, UML-B converter. Rodin platform [6] is suitable to create model and some tools compactable with Rodin as B2C# and UML-B tools. The benefit of this combination isn't integrating requirements, codes and verification in system development life cycle only, but also the consistence refinement, verification with high automation, reusability model and detection of anti-patterns problems. The proposed approach can also be applied on any mathematical algorithm with some updating; I will discuss this in details in the proposed approach section. An ATM model is presented to demonstrate the proposed methodology
The rest of this paper is organized as follows: section 2 presents the related works. Then we will introduce The Proposed Approach in section 3. Then the proposal will be applied on the ATM model in section4. Section5 and 6 will present the result analysis and conclusion. Finally, the references are viewed in section7.

2. Related works
Software quality was ameliorated by several techniques. Design pattern was presented as a good solution in [7]. Also reference [8] presented metric approach to detect five types of UML anti-patterns. But [4] displayed a prototype approach to detect anti-pattern certainly for MOF; based modeling language. Reference [9] presented survey about many formal methods that have been proposed in recent years to improve the software quality. This approach includes specification and modeling languages as well as formal verification techniques, such as model checking, and theorem proving.

3. The Proposed Approach
In this section, a brief description for the phases depending on Rodin platform will be displayed to generate the validation code. The proposed phases are shown in figure 1. I have discussed the phases for UML class diagram model. In case of algorithm the phases are similar but the problem of algorithm anti-

patterns needs to be discussed for different kinds of algorithm's anti-patterns. The following is the phases' description.

First phase is converting UML class diagram model to event B model. That is by UML-B**.** UML-B provides Packages, context, class and state machine diagrams in event B [10]. The semantics of a UML-B model is given by the Event-B generated by the UML-B tool according to a set of translation rules. Each UML-B machine gives rise to both an implicit Event-B context and machine. The context is used to define types for the classes and states in the UML-B machine. Event-B components as machine, classes, class attributes and associations become variables. Events and transitions in classes and state machines become events in the generated Event-B machine. Figure2 is showing abstract overview of UML-B. The figure2 shows a package diagram which has a class diagram containing class cls1 and cls2 then properties of class and properties of association of At2 finally, a State machine *stm* of class cls1. Figure 2 presents respectively, package diagram, class diagram, properties of class, properties of association and state machine.

In the generated Event-B machine, the class cls1and cls2 give rise to variables. The class cls1 consists of the attribute at1 of type N and also the association at2 of type cls2.

The generated Event-B machine for machine1 is shown in the Rodin screenshot of Figure 3. Each Event-B statement is preceded by its label, which describes its purpose.

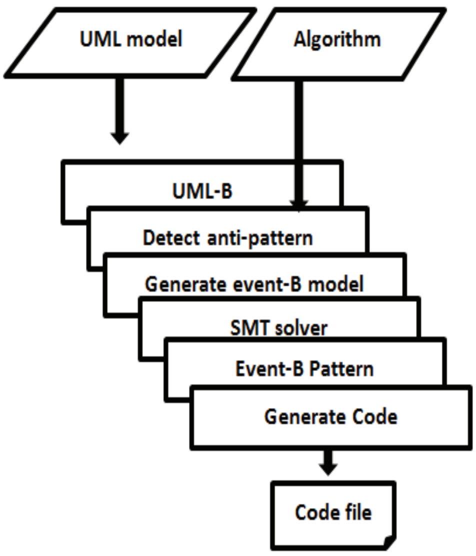


Figure 1 the proposal approach phases

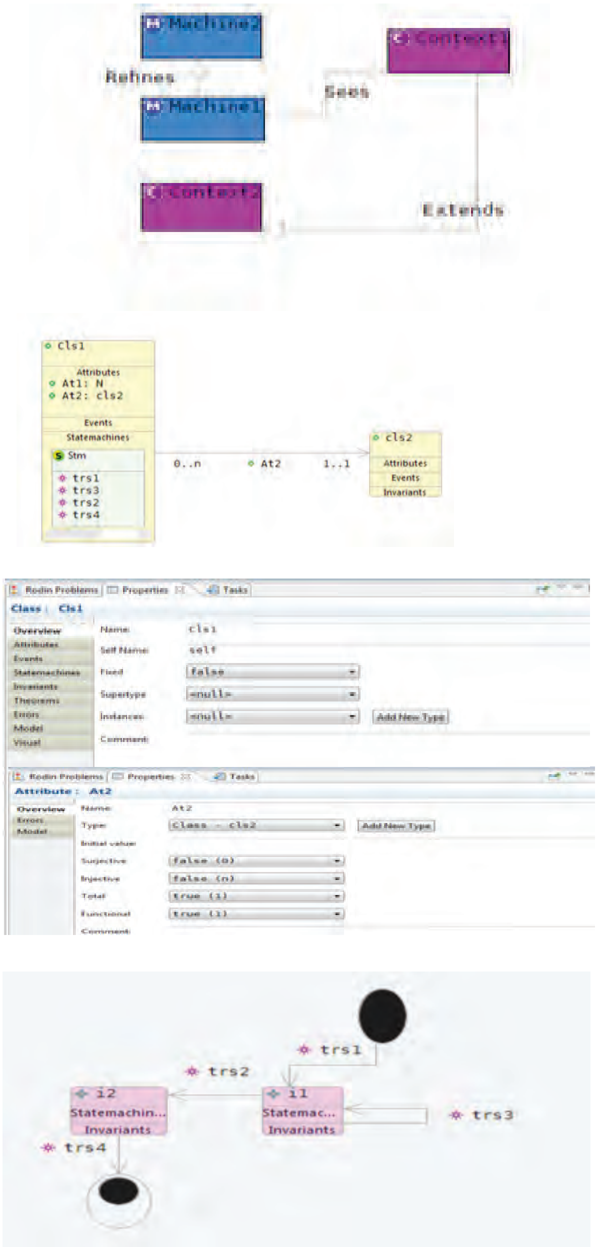


Figure 2 UML-B abstract diagrams

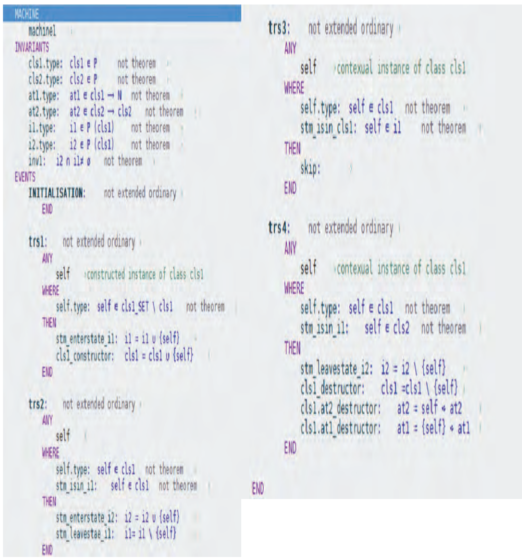


Figure 3 Generated Event-B specification of machine1

The second phase is detection UML anti-pattern problems. When you want to construct models, you should be alert for anti-patterns and correct them. That is to send a consistent correct pattern to the next phases. An anti-pattern is some kind of problem in software project situation. The UML Anti-pattern was classified into three main parts; semantic class, behavior class and structure class. Our proposal detects the structure class. That is by creating event-B model and solving the problems.

The third phase is Refinement Approach in UML-B. Generally, the refinement techniques concerning the concept of refined classes and inherited attributes are described briefly from [10]. The benefit from refined classes and inherited attributes is performing refinement in Event-B. The refinement of classes and inherited attributes in UML-B reflects the refinement of variables in Event-B. A refined class is one that refines a more abstract class, and an inherited attribute is one that inherits an attribute of the abstract class. Some elements of an abstract UML-B model needs to be retained by the refinement in UML-B.

From [10] in Event-B refinement, may drop some of the variables and may introduce new variables. But in UML-B refinement, a machine that refines a more abstract machine may contain refined classes where each refined class refines a class of its abstract machine. Therefore, the motivation for refined state machines and refined states comes from combining the state machine hierarchy in UML-B with refinement in Event-B so in UML-B refinement; a machine may contain refined state machines and refined states.

The fourth phase is using Satisfiability Modulo Theory (SMT) solver. The Satisfiability Modulo Theory (SMT) problem is a decision problem to determine if a given logic formula is satisfiable with respect to a combination of theories expressed in first-order logic. Theories of interest for the work described in this work include un-interpreted functions with equality and integer arithmetic. Since the validity of a proof obligation can be decided by checking the un-satisfiability of its negation, SMT-solvers are natural candidates for discharging the verification conditions generated in the application of Event-B methods. SMT-solvers can for example handle a formula like

$$x \le y \wedge y \le x + f(x) \wedge P(h(x) - h(y)) \wedge \neg P(0) \wedge f(x) = 0$$

Which contains linear arithmetic on real's (0,+,−, ≤), and un-interpreted symbols (P,h,f). SMT-solvers use decision procedures for the disjoint languages (for instance, congruence closure for un-interpreted symbols, and simplex for linear arithmetic) and combine them to build a decision procedure for the union of the languages. The ability to handle quantified formulas as well as to construct certificates (proofs) of their results. SMT solver used to increase the automatic proof in event-B model [11].

The fifth phase is design Event-B Pattern. Design Patterns in Event-B is to have a methodological approach to reuse former developments (referred to as patterns) in a new development. The pattern's approach is a tool for building domain models for inexperienced designer [12].The proofs of the pattern can be reused too. It was shown that for the special case as a model, but this model can't see any context and also its events haven't any parameters, the generation of a refinement of the problem at hand is correct by construction, and no need to generate PO again. The correct merge between the problem and pattern is criterion for correct constructive. Once all checks are done, the refinement of the problem is generated by merging the pattern refinement with the problem. Then save the model as a pattern saves the proof for increasing the degree of automation.

The sixth phase is the code generation. The Code generation philosophy is automatic generation of source code may be regarded as an "open-loop" refinement step. When there is not static equivalence checking against the previous refinement is possible. It classified into three steps rewriting, converting and building.

- The Rewrite step

After final refinement step and converted the final model to be a pattern, then using an easily translatable subset of event-b. First, in the context each constant converts to its literal value. The guards *Guds* range convert to comparison statements. Abstract sets convert to its numerical meanings via mapping functions. Also the global variables are disallowed from the right of assignments and must be restated as intermediate local variables. But logical OR is not supported. So we solve this by divided events with this type of guards into two events. Also we can merge events. This convert requirement does not contribute to the translation process, but enforces division of events into simplest form.

- The converter step

Once pattern has been converting manually, all selected events- without explicit- was translated automatically. A single file is produced for each called "leaf machine".

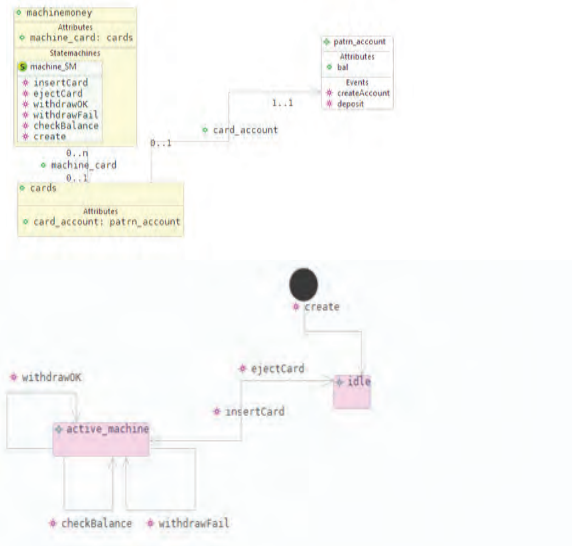
For example B2C# converter is invoked by a single user action. This step classified into two steps: first is the event translation and the second is calling function generation.

- The Build step

Once automatic converter of the Event-B model is complete, an execution environment must be provided and compiled by a suitable development tool chain. Implementing functions must be provided for all un-interpreted functions as instrumentation and deadlock functions. The file generated after define file “EventbIncludes.h” whose inclusion has been automatically inserted. A top-level main function must be provided to call the generated functions “INITIALISATION” and “Iterate”.

4. Case Studies

The ATM is a public application many searcher work in many fields. An auto teller machine ATM is a machine that allows bank customers to do some of the banking transactions 24 hours per day. The practical application was created by Rodin platform. The first phase is convert ATM class diagram to event-B model. The figure 4 was showed UML-B specification of the ATM abstract machine. The abstract machine consists of a class Account with its attribute BAL and four events namely, create Account, deposit, withdraw and check Balance. The Account class represents the set of accounts that currently exist in the system. The attribute *BAL* represents the balance of an account. The withdraw event has added am parameter with type natural number. The parameter is shown in the property view in figure 4. It includes the guard and action. *self* is the self-name property defined for the class Account. If the amount, am, is less than or equal to the balance in the account, then the withdraw event occur.



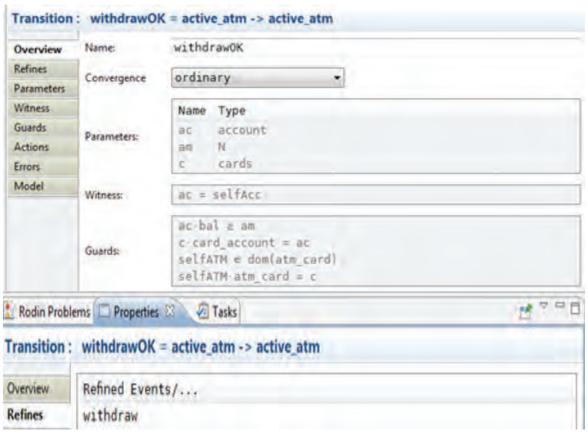


Figure 4 UML-B specification of the ATM abstract machine

The second phase is anti-pattern detection to solve it. The following examples present some structure anti-patterns. Figure 5 presents Anti-pattern in package diagram when loos association. The error description list leads designer to know that. Also figure 6 shows “Parameter Has Invalid Default data type anti-pattern” and how event-B detects it. Another example is “Invalid expression constrain anti-pattern” as shown in figure 7.

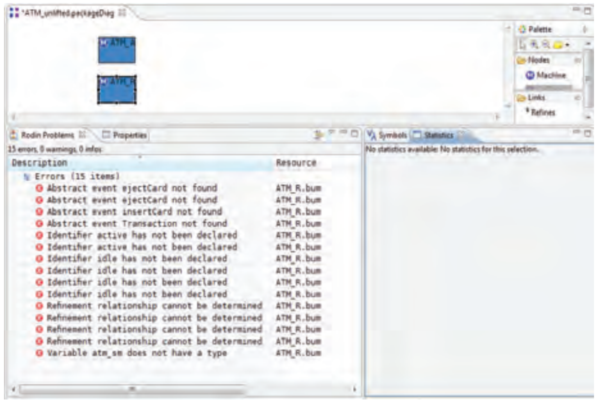


Figure 5 lost association in package diagram anti-pattern

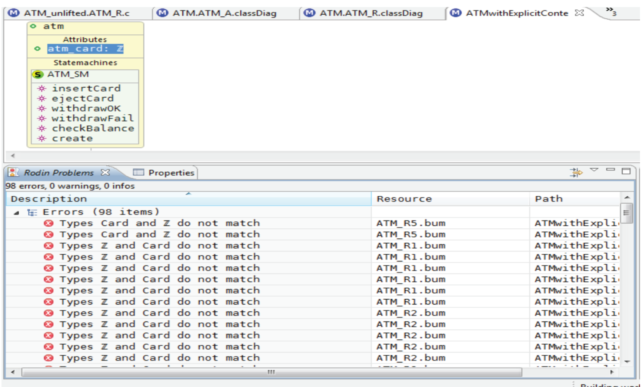


Figure 6 parameter Has Invalid Default Data type anti-pattern

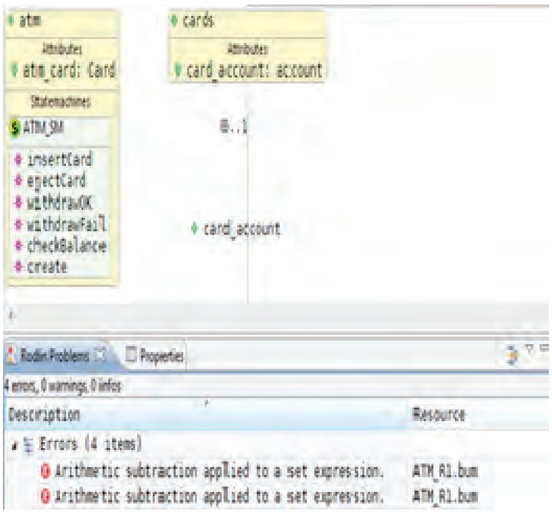


Figure7 invalid expression constrain anti-pattern detection

Event-B detect anti-pattern and also supports designer to solve the anti-pattern as shown in figure 8. When a designer selected any row from problem list, he can read the exactly place of error in event B language.

We have continued detection anti-pattern since the problem list empty as shown in the figure 9. It presents the final iteration in the second phase.

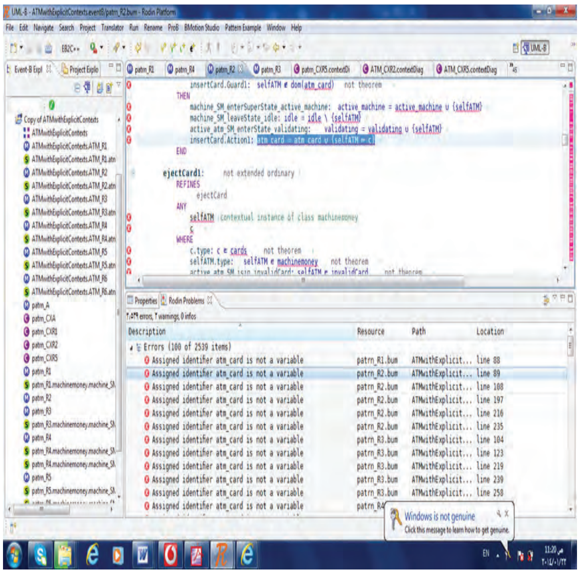


Figure 8 event B supports to solve structures anti-patterns

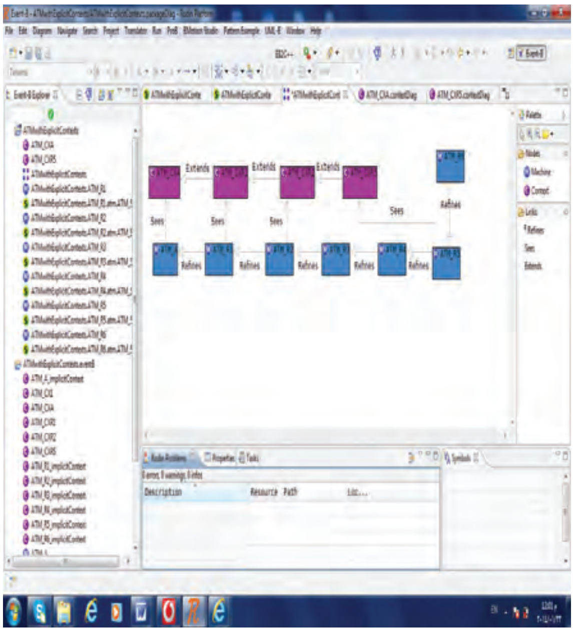


Figure 9 the final iteration in second phase

The third phase is generate and refinement the ATM model. We discussed in more details seven refinements to ATM model in [13].

The fourth phase is applied SMT solver to increase the automation degree by decrease the proof obligation. We used Automatic verification of proof obligations as SMT-solvers. The plug-in communicates with the SMT-solvers using files and operating system commands.

The configuration of the plug-in includes a choice of SMT-solvers. It is now available to the formal methods community as an exploratory package through Rodin's official source code repository. Currently, the verification with the SMT-solver has to be activated by clicking a button as shown in left part in Figure 10. Whenever the verification is successful as shown in right part in Figure 11, where the status of the proof obligation is updated and then the user may move to the next proof obligation.

The fifth phase is design pattern that is by the plug-in provides a wizard, which taking users through different steps namely, matching, checking syntax, renaming and incorporating. We can see the details of applying pattern in [8]. This phase is important to save proofs.

Event-B	C #
n..m	int
x ∈ Y	Y x;
x ∈ n..m → Y	Y x[m+1];
x :∈ Y	/* No action */
x ≥ y	if(x>=y) {
x = y + z	x = y + z;
x = y – z	x = y - z;
x = F(y)	F(y,&x);
(a↦b) = F(x↦y)	F(x,y,&a,&b);
x = a(y)	x = a(y);
x ≔ y	x = y;

Table 1 sample of rewriting table

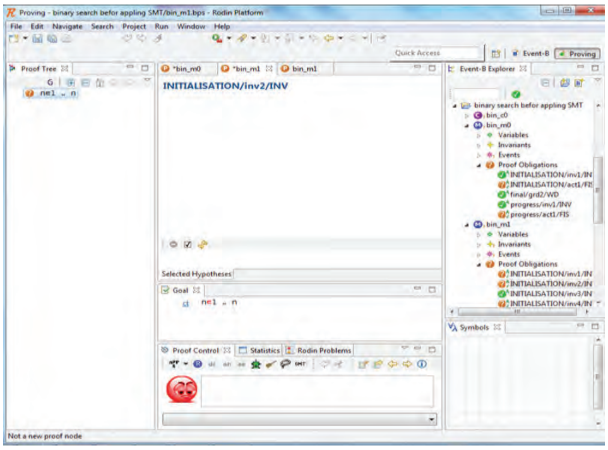


Figure10 the screen shot of the proof before the SMT proof, the button is active and the status is not proved

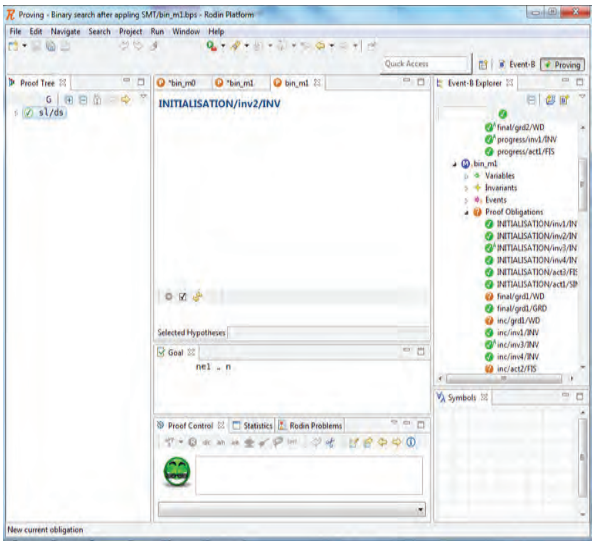


Figure 11 The screenshot of the proof after a successful proof, the button has been dis-activated and the status is ''proved''

The sixth phase is Automatic C# Code Generation for ATM Pattern Model. The strong constrain to start this phase is received model to 100% was Proofed, so we used SMT solver to increase the PO as we can. That's to decrease the manually proof.

Now in brief the three generation code steps will present in C# code by using B2C# plugin and it's the same for Java programming language. The different from language to another is in the first manual step. It is the rewriting step. Where designer make some changeable as in the table1. That is for static traceability between model and source code, and also dynamic traceability between model and executable file. There isn't any problem with generate looping recursive or iteration, until deadlock condition detected automatically.

Then the second step is Convert ATM Pattern. Event converter of ATM Pattern that is will be done by converting each event of event-B ATM model to an individual C# function. See the following example in figure 12. After designer has converted events, Calling Function automatically inserted as a trigger.

```
    Transaction  ≙
    STATUS
        ordinary
REFINES
        Transaction
WHEN
        active_sm_isin_validating  :  active_
THEN
        active_sm_enterState_dispensing  :  a
                                           END
```

```
private bool Transaction()
{
/* Guards No. 1 */
if(active_sm ==
validating){

        /* Actions */
        active_sm =
dispensing;
        return
true;}
```

Figure 12 Event converter for Transaction event

Finally, Building of the top-level C# main function must be provided to call the generated functions "INITIALISATION" and "Iterate". The calling of INITIALISATION function of ATM model must be called before Iterate.

```
/* Translation Begins Here */

using System;

using System.Collections.Generic;

public class mini_1{

/* Global Constants defined of [mini_ctx] */

const long[] f=new long[1000]; /* C# array
declaration when constant is given in range of
predicate */

/* No translatable type found for [n] */

/* Global variables defined in [mini_1.mch] */

ulong m; /* Integer in range undefined */

int p; /* Integer in range */

int q; /* Integer in range */

public bool INITIALISATION()

public bool Iterate()
```

Figure 13 Part of ATM C# derived code

5. Analysis of the Results

The following statistics of PO (Proof Obligation) criterion generated from ATM UML-B different models are shown in table 2. We note that Rodin model can't prove the model automatically 100% so we also can't generate code from Rodin event B model directly. But the proposed approach in this paper tends to increase automatically the proof obligation and save it.

Also we compared between manual and automatic code generation by RSM (Resource Standard Metrics); a quality analysis open source tool [14]. This has been applied on ATM refinement models. We note that the complexity average decrease 60% and all the other RSM features have been ameliorated in the automatic generation code in our approach. This is shown in figure 14a and 14b.

Methods / refinement	Total POs	Rodin (Auto proof)	Interactive (SMT)	Total POs %	Saved Proof	Undercharged
ATM_A	5	4 80%	0	4 80%	0%	1
ATM_1	35	23 65%	12	35 100 %	0%	0
ATM_2	169	40 23%	128	168 99%	0%	1
ATM_3	156	35 22%	112	147 94%	0%	9
ATM_4	186	36 19%	133	169 91%	0%	17
ATM_5	358	114 32%	204	318 89%	0%	40
ATM_6	53	30 57%	23	53 100 %	0%	0
ATM_7	88	44 (50%)	37	81 92%	100 %	7

Table 2Proof Obligation of ATM refinements models after apply the proposed phases

```
Avg eLOC ..............:       20.00
Avg Cyclomatic Comp. ..:        4.33
Avg Parameters ........:        0.00
Avg Comment Lines .....:        3.67
Avg Physical Lines ....:       32.33
Avg LOC ...............:       28.00
Avg lLOC ..............:       15.00
Avg Interface Comp. ...:        1.00
Avg Return Points .....:        1.00
```

Figure14 a RSM quality report for automatic generation ATM code for first refinement

```
Avg eLOC ..............:        5.00
Avg Cyclomatic Comp. ..:        2.60
Avg Parameters ........:        0.00
Avg Comment Lines .....:        1.70

Avg Physical Lines ....:       12.70
Avg LOC ...............:        7.80
Avg lLOC ..............:        4.10
Avg Interface Comp. ...:        2.40
Avg Return Points .....:        2.40
```

Figure 14 b RSM quality report for manual ATM code for first refinement

6. Conclusions and Further Works

In this paper I proposed an approach that integrates Event-B and Pattern to enhance the software quality and detect the anti-patterns problems. The proposed approach improves the proof obligation by SMT solver. The benefit of applying the proposed approach isn't integrating requirements, codes and verification in system development life cycle only, but also the consistence refinement, verification with high automation, reusability model and detection anti patterns problems. When I applied the proposed phases on the ATM refinements, I conclude by proof obligation criterion that using the proposed phases increase the automation and save the proof 100%. And also detect structure anti-pattern in UML class diagram model. Finally, the complexity average and all features in RSM report show the increasing quality of the automatic generated code. In the future, we are going to enhance the code anti-patterns and propose a new approach to detect semantic UML anti-patterns. We will also explore the link between formal methods and other UML diagrams.

7. References

[1] J. Abrial, M. Butler, S. Hallerstede, T.Hoang, F.Mehta, L. Voisin . Rodin: an open toolset for modelling and reasoning in Event-B., International Journal on Software Tools for Technology Transfer (STTT) (6) 447–466, 2010.

[2] http://www.altova.com/umodel.htm l accessed at Nov.2013

[3] M.Balaban, A. Maraee, A. Sturm. Management of Correctness Problems in UML class Diagrams Towards a Pattern-Based Approach. International Journal of Information System Modeling and Design (IJISMD), 1(4), 24-47, 2010.

[4] M. Elaasar . An Approach to Design Pattern and Anti-Pattern Detection in MOF-Based Modeling Languages. , Doctoral Dissertation, Carleton University, Canada, 2012.

[5] W.Brown, R. Malveau, H. McCormick, T. Mowbray. Anti-patterns: Refactoring Software, Architectures, and Projects in Crisis, 1st edn. John Wily and Sons,West Sussex 1998.

[6] S.Wright, .Using Event B to Create a Virtual Machine Instruction Set Architecture Abstract State Machines, B and Z. Springer Lin 2008

[7] M.Dodani,. Patterns of anti-patterns. Journal Of Object Technology 5, 29–33 2006.

[8] R. Fourati, N. Bouassida, H. Ben Abdallah Miracl . A Metric-Based Approach for Anti-pattern Detection in UML Designs. Computer and Information Science journal, SCI 364, pp. 17–33 2011.

[9] E. Elsayed, G.El-Sharawy, E.El-Sharawy, .Enhancing Event-B Pattern. LAMBERD academic publishing, Germany. .2013.

[10] M.Said, M.Butler,C.Snook, . Language and Tool Support for Class and State Machine Refinement in UML-B. ECS, University of Southampton, Southampton, SO17 1BJ, UK. 2009.

[11] F.Maturana, R.Staron, .Emerging Solutions for Future Manufacturing, chapter: An Intelligent Agent Validation Architecture for Distributed Manufacturing Organizations. Springer Berlin Heidelberg publisher 2005.

[12] E. Elsayed, G. El-Sharawy, E. El-Sharawy.Integration Of Automatic Theorem Provers In Event-B Patterns. IJSEA Vol. 4 No. 1 2013 http://www.airccse.org/journal/ijsea/current2013.html .

[13] E. Elsayed, G. El-Sharawy, E. El-Sharawy,.The Refinement Validation Of ATM Model By Using UML-B. International Research Journal of Engineering and Technologies IRJET Vol. 5 Issue 7, Science Record journal, Academic Information Press, Delaware, USA. Jun 2013.

[14] http://msquaredtechnologies.com/m2wizard/rsm_wizard.php accessed at Oct. 2013.

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Unit Commitment Using a Hybrid Differential Evolution with Triangular Distribution Factor for Adaptive Crossover

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Abstract

In the present day power scenario Unit Commitment (UC) is one of the complex challenging tasks for power system operators. UC is a nonlinear, non-convex, large scale, mixed integer problem. To mitigate this complex problem in this paper a hybrid Differential Evolution with local search technique and an adaptive Crossover using triangular distribution factor (DE-TCR) is presented. The salient features of the proposed DE-TCR are: An intelligent chromosome representation is used which is independent of number of units present in UC problem thereby reducing the length of chromosome. It is able to interlink the cross over probability in conjunction with the non-separable and decision variable dependency of UC problems. Local search using Sequential Quadratic Programming, which has proved in improving the performance of the classical DE algorithm. Initially, the proposed DE-TCR is used to determine an optimal generation schedule for each hourly demand. Later, SQP is utilized to find the optimal dispatch strategy to minimize the fuel cost.

The effectiveness of the proposed algorithm is tested on standard 4 units, 8 hour and 10 units, 24 hour UC systems. Results demonstrate that the proposed algorithm can perform better and produce global optimal solutions compared to that of other reported methods.

Keywords: *Unit Commitment, Differential Evaluation, Sequential Quadratic Programming, Adaptive cross over and Triangular Distribution factor.*

1. Introduction

Generation scheduling or Unit Commitment (UC) is the problem of finding the optimal number of generators which are to be turned on and off according to the time varying load demand so that the solution is a global optimal economically. Further, the solution should also satisfy the standard UC constraints such as spinning reserves, minimum Up and Down time of units, ramp rate limits, crew constraints etc,. In the present day power scenario, under the deregulation environment the problem of generation scheduling is highly complex because of the increase in the number of generators, type and size of generating facilities, and also due to time varying load demands. Further, from the solution of optimal schedule obtained for the UC problem, a dispatch strategy should be found among the committed generators which should give a minimum fuel cost. This problem is known as Economic Load Dispatch (ELD). As a result the focus today for the power system engineers is to find a global optimization strategy which can solve the problem of UC and ELD in most economical and reliable manner [1].
From the literature available it is understood that there are many approaches available to solve the complex problem of UC and ELD. All those methods reported have its own advantages and disadvantages [2]. In general these methods can be classified as conventional, heuristic and hybrid of these. Conventional method includes Exhaustive Enumeration [3], Priority Listing [4-5], Dynamic Programming (DP) [6-7], Integer Programming [8-9], Branch and Bound [10], Lagrangian Relaxation methods (LR) [11], Sequential Quadratic Programming (SQP) [12]. All these conventional approaches suffers from the drawbacks of the dimensionality of the problem and further, these methods cannot handle the constraints of UC problem effectively which in many cases results in sub optimal solution. Heuristic approaches like Tabu Search (TS) [13], Simulated Annealing (SA) [14], Expert systems [15], Fuzzy Systems [16], Artificial Neural Networks (ANN) [17], Genetic Algorithm (GA) [18-19], Evolutionary Programming (EP) [20-21], Ant Colony

Systems (ACS) [22-23], Particle Swarm Optimization [24], Differential Evolution (DE) [25-26], Self Adaptive DE [27], Bacterial Foraging (BF) [28], Imperialistic Competition Algorithm (ICA) [29]. Though these methods overcome the drawbacks of conventional approaches it suffers from high computational time. At present, hybrid of heuristic and conventional methods is implemented to solve the problem of UC and ELD. These hybrid methods include GA-PSO [30], GA-SaDE [31], Fuzzy assisted Cuckoo search algorithm [32]. These techniques exploits the advantages of conventional and heuristic search in an effective way thereby handling the complex problem better even with the consideration of all UC and ELD constraints. In the hybrid approaches the major crux lies in the way these methods are hybridized, based on which the performance of these methods varies with one another. Out of all these hybrid methods, algorithms that are based on Differential Evolution [DE] are the most simple and effective one [33].
However some drawbacks can be seen in DE approach along with GA approach. Few of them are: restriction to apply for problems with limited control variables, no guarantee for solution to be globally optimum, higher computational time etc.
Recently Differential Evolution with Adaptive Crossover based on Triangular distribution Factor (DE-TCR) [34] is implemented for various complex optimization problems. The following *merits* may be observed in DE-TCR approach:

- The method avoids the unnecessary increase in the size of DE chromosome.
- Problem-specific operators incorporated in the DE method makes the method suitable for solving UC problem.

In this paper DE-TCR is implemented for UC problem and SQP is used for ELD problem. The simulation results using DE-TCR of various optimization problems are found to be more promising and very attractive.

The remaining paper is organized as follows: Section 2 deals with the formulation of UC-ELD problem. Section 3 describes the intelligent chromosome representation and DE-TCR algorithm. Section 4 deals with the implementation of proposed DE-TCR and SQP for UC-ELD problem. Numerical results and discussion are presented in Section 5. Finally conclusions are drawn in Section 6.

2. Formulation of UC- ELD Problem

The objective function of UC-ELD problem is a minimization function (1) which is composed of the unit operating cost (fuel cost), the startup cost of the unit at any given time. Hence the Combined Objective Function is as given below [1]

$$MinCOF = \sum_{t=1}^{NT}\sum_{i=1}^{NG} FC_{i,t}U_{i,t} + SC_{i,t}(1-U_{i,(t-1)})U_{i,t} \qquad (1)$$

Subject to

(i) Power balance constraint

$$\sum_{i=1}^{NG} P_{i,t}U_{i,t} = PD_t \qquad (2)$$

(ii) Generator real power min-max constraint

$$P_{i,\min} \le P_{i,t} \le P_{i,\max} \qquad (3)$$

(iii) Minimum Up/Down time constraint

$$T_{i,t}^{on} \ge MUT_i \qquad T_{i,t}^{off} \ge MDT_i \qquad (4)$$

(iv) Spinning Reserve constraint

$$\sum_{i=1}^{NG} P_{i,t}^{\max}U_{i,t} \ge PD_t + R_t \qquad (5)$$

(v) *Ramp up/down rates*

$$P_{i,\max}(t) = \min\{P_{i,\max}\, P_i(t-\mathbf{1})\} + \tau RU_i \qquad P_{i,\min}(t) = \max\{P_{i,\min}\, P_i(t-\mathbf{1})\} + \tau RD_i \qquad (6)$$

Where

$FC_{i,t} = a_i + b_iP_{i,t} + c_iP_{i,t}^2$ is the fuel or production cost of the i^{th} unit at given time 't', whereas a_i, b_i and c_i are the cost coefficients and $P_{i,t}$ is the amount of real power generated in the i^{th} unit.; $SC_{i,t}$ is the generator Start Up cost of i^{th} unit at given time 't' ; $U_{i,t}$ denotes the unit ON/OFF status. $U_{i,t}=1$ represents ON state of i^{th} unit at given time 't' and $U_{i,t}=0$ represents OFF state of i^{th} unit at a given time 't'; PD_t is the real power demand at a given time 't'; $T_{i,t}^{on}$ is the total time for which the i^{th} unit is turned ON at a given time 't'; $T_{i,t}^{off}$ is the total time for which the i^{th} unit is turned OFF at a given time 't'; MUT_i is the minimum up time for the i^{th} unit; MDT_i is the minimum down time for the i^{th} unit; $P_{i,max}$ is the maximum power limit of i^{th} unit ;$P_{i,min}$ is the minimum power limit of i^{th} unit; RU_i is ramp up rate for i^{th} unit; RD_i is the ramp down rate for i^{th} unit; τ is the UC time step (60 min.).

3. General Purpose DE-TCR Algorithm

The global optimal solution for the UC problem is very difficult to obtain, as the search has to be carried amongst the large number of populations. The proposed DE-TCR algorithm applied to UC has the following requirements:
1. Need for representing the chromosome intelligently, that reduces size and number of populations.
2. Need for designating the Problem-specific operators those are incorporated in the DE method effectively that

creates less number of generations and populations.
3. Need for a Local search method that deals with more feasible solutions and avoid infeasible solutions.

This section provides designing of chromosome and problem specific operators like mutation and cross over operators. Also, this section discusses the modifications in operators that bring developments in the DE-TCR approach. Finally the general purpose DE-TCR and SQP algorithms are presented.

3.1 Intelligent chromosome representation

The competency in solution not only depends on the algorithm which is used, but also depends on the methodology by which the problem is encoded in the algorithm. Therefore to improve the efficiency of the algorithm an intelligent solution (chromosome) representation is done as explained below.

- *Conventional coding*

In the conventional approach the length of each decision variable is equal to the product of number of generators (NG) and the total hours (NT) for

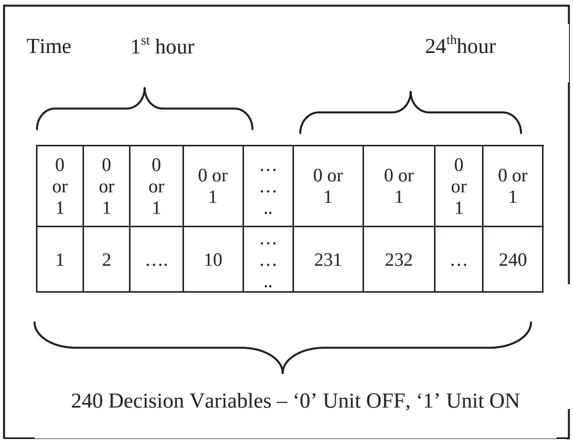

Figure 1: Coding of Decision Variable in conventional approach

which the power demand schedule is known. For example if NG=10 and NT =24 hrs, then the length of decision variable is 240 as shown in Figure 1.

With the increase in number of generators, the length of decision variable increases accordingly which will produce a detriment effect in the solution by either introducing slower convergence or landing in sub optimal solution.

- *Intelligent coding*

In this approach a decimal number in between ‘0’ to ‘1’ is coded in each segment of decision variable. This value is multiplied with the decimal equivalent to the size of generators in binary form. Then this decimal number is converted to its equivalent binary of length equal to the size of generators. For example if NG =10 and NT =24 then the length of decision variable is 24. Say, a segment of decision variable represents a decimal number 0.7321, then this value is multiplied with the decimal number 1023 (*which is the equivalent binary of* ‘1111111111’ *when all unit is ON*) which is ‘1011101100’ as shown in Figure 2.

Time	1 hr	2 hr	3 hr	……	23 hr	24 hr
Generator ON/OFF	0-1 Dec	0-1 dec	0-1 Dec	……	0-1 dec	0-1 dec

Figure 2: Representation of Decision Variable in the proposed approach

This approach ensures that the maximum length of decision variable for any size of system will not exceed 24. Further the search space is limited to ‘0’ to ‘1’ which makes the algorithm stronger in landing at global optimal value with reasonable population size and generations.

3.2 Algorithm of DE-TCR

DE is developed by Storn and Price in 1995 [35]. The major advantage of DE is its simple theoretical frame work; relatively few control variables and require less computational time with proven convergence to global optimality. In this section the fundamental algorithm of DE and the modified versions of DE known as SaDE and DE-TCR are presented.

3.2.1 The fundamental DE Algorithm

The fundamental DE algorithm is as explained below:

- *Population Initialization*
  Similar to other Evolutionary Algorithms, DE starts with a randomly generated initial population with N dimension of size NP. Each individual x is within the interval [lb, ub].
- *Mutation*
  For each individual, select 3 random other individuals (x_1, x_2 and x_3) from the population. Using one individual say x_1 as base and other two x_2 and x_3 as differentiation vector, form the mutant vector v as

$$v = x_1 + f(x_2 - x_3) \quad (7)$$

  Where f is a scale factor which controls the difference vector.
- *Cross Over*
  DE utilize uniform crossover to generate new individual z using

$$z = \begin{cases} v & \text{if rand} \le \text{C} \\ x & \text{otherwise} \end{cases} \quad (8)$$

Where rand is a random number taken from the interval [0, 1] and C_r is the crossover probability. If Z

exceeds the boundary limits, reinitialize it.

- *Selection*
  The above process is repeated and their corresponding fitness is evaluated. If the function value is better than the old individual then replace the old individual with the new one and repeat the complete process of mutation, cross over and selection until maximum generations or convergence is attained.

3.2.2 Self Adaptive DE Algorithm

Though DE outperforms other known heuristic methods, in most of the optimization problems it suffers from the drawback of conventional procedure for crossover operator 'C_r'. In conventional procedure, the value of 'C_r' remains constant which may lead to local optimal values. Hence a self adaptive DE was introduced in [31]. In this procedure the values of the control parameters 'f' and 'C_r' are varied based on evolution during the run. Both these values depend on the individual chromosome. For each individual these control parameters are changed as follows

$$f_{i,g+1} = \begin{cases} f_l + rand_1 * f_u \text{ if } \mathrm{rand}_2 < \tau_1 \\ f_{i,g} \quad \text{otherwise} \end{cases} \tag{9}$$

and $$Cr_{i,g+1} = \begin{cases} rand_3 \quad \text{if } \mathrm{rand}_4 < \tau_2 \\ Cr_{i,g} \quad \text{otherwise} \end{cases} \tag{10}$$

where $\tau_1 = 0.1$ and $\tau_2 = 0.1$ are the probabilities to adjust control parameters '*f*' and 'C_r' and $f_l = -1.5$ and $f_u = 1.5$ are the lower and upper bounds. Since the updated values of '*f*' and 'C_r' were taken before the operation of mutation, which in turn influence mutation, crossover and selection. This adaptation of DE operators helps to converge much faster when compared to the conventional DE algorithm.

3.2.3 DE with Triangular distribution factor for Crossover (DE-TCR)

From [34] it is understood that for separable problems low value of 'C_r' is suggested and for non-separable problems high values are suggested. SaDE does not take this factor into account. Hence a novel DE algorithm with triangular distribution factor for '*f*' and 'C_r'according to the complexity of the problem is introduced in [34]. The salient modules of the proposed DE-TCR are (a) Adaptive Cross over (b) Local search using SQP.

3.2.3.1 Adaptive Cross Over with triangular distribution factor

Initially in DE-TCR three different (triangular) distribution factor for 'C_r' such as minimum (mincr), median (medcr) and maximum (maxcr) between the ranges '0' to '1' are considered. Then based on a random number ('rand', between 0 to 1), every chromosome is assigned its own 'C_r' value using the formula given below.

$$\begin{aligned} &\text{If rand} < [(\text{medcr - mincr}) \times (2/(\text{maxcr - mincr})) \times 0.5] \\ &Cr = \min cr + \sqrt{rand \times (\max cr - \min cr) \times (medcr - \min cr)} \\ &else \\ &Cr = \max cr - \sqrt{(1 - rand) \times (\max cr - \min cr) \times (\max cr - medcr)} \end{aligned} \tag{11}$$

The adaptive mechanism at the end of every generation changes the triangular values of 'C_r' based on number of success recorded i.e. if the success recorded is greater than the success rate. A success is said to be obtained if the fitness value of a child or offspring is better than the parents, following which the child replaces the parent in the next generation. A success rate is fixed at the start of generation, which is a fraction of the total number of chromosomes or a population set. For each number of success recorded, the corresponding 'C_r' value is also stored in a variable 'successor'. At the end of each generation, the triangular distribution factor for cross over is adapted according to the formula as given below.

$$\begin{aligned} &\text{If success recorded} > \text{success rate} \\ &\quad \text{successcr1} = \text{sort in ascending (successcr)} \\ &\quad \text{mincr} = \text{first element of successcr1}; \\ &\quad \text{medcr} = \text{mid element of successcr1}; \\ &\quad \text{maxcr} = \text{end element of successcr1}; \\ &\text{end} \end{aligned} \tag{12}$$

In the next generation, the triangular distribution factors adapted using (12), is used in (11) to compute new values of 'C_r' for each chromosome. On the other hand the distribution factor for '*f*' to compute mutant vector using (7) is a fixed one throughout the process. Depending on the values of 'C_r' this adaptive mechanism selects the following type of cross over as given below:

If $C_r < 0.5$ – Binomial cross over

If $0.5 < C_r < 0.95$ – Combines Binomial and Line recombination based on a random number

If $C_r > 0.95$ – Line recombination cross over

Hence this adaptive mechanism is able to detect non-separable problems with high values for 'C_r'. Also this algorithm is capable to detect a strong dependency on decision variable and use a non- rotationally invariant line recombination.

Further, a population refreshment technique is incorporated when the difference of interquartile range (IQRrange) is below population refreshment rate. The interquartile range (IQRrange) is the difference between the 75th and 25th percentiles of population.

3.2.3.2 Local search using SQP algorithm

The sequential quadratic programming (SQP) [36] routine is executed in every child of the population with a probability α_{LS}. Local search strategies proved to improve the performance of the classical DE algorithm [37]. The probability to apply local search in every child is given by the following formula.

$$\alpha_{LS} = 1 - \frac{1}{100 \times \text{no. of Decission variables}} \tag{13}$$

The condition to be satisfied to perform local search in each children is as given below.

$$\begin{array}{l} \text{If rand} < \alpha_{\text{LS}} \\ \quad \text{perform local search using SQP algorithm} \\ \text{end} \end{array} \tag{14}$$

where 'rand' is any random number between [0 to 1]. The detailed procedure of the general purpose SQP algorithm is explained in section 3.2.5.

3.2.4 General Purpose DE-TCR Algorithm

The general purpose DE-TCR algorithm is given below

Step 1: Initialize populations with N dimension (decision variables) of size NP. Each individual x is randomly selected from the searching space within the interval $[lp, up]$.

Step 2: Evaluate initial population

Step 3: For k=1 to Maximum generations or convergence criterion reached

Step 3.1: Apply the fundamental DE operators on NP to get the offspring

1) Perform mutation operation with *f* selected from the triangular distribution.

2) Perform crossover operator C_r selected from the triangular distribution.

Step 3.2: For every child, perform a local search with a probability of α_{LS}

Step 3.3: Evaluate offspring; if child ≤ parent, the parent is substituted by its child.

Step 3.4: Record the number of success. If the cumulative number of success is bigger than $r_{success}$, reset the cumulative number and recalculate the triangular distribution for C_r.

Step 3.5: If IQR < V, refresh the population with $x^{median} \pm \gamma_{\text{var}} \times V$ Where $V = (x^{*}_{upper} - x^{*}_{lower}) / \gamma_{\text{var}}$ x^{*}_{upper} and x^{*}_{lower} are the bounds of chromosomes since the last population refreshments. γ_{var} is the threshold of IQR between 0 to 1.

Step 4: Algorithm terminates.

3.2.5 General Purpose SQP Algorithm

In general a nonlinear constrained optimization problem is defined as given below

$$\min \ f(x) \tag{15}$$

Subject to

$$g_i(x) = 0 \quad \text{for i} = 1,2,......\text{m}_\text{e} \tag{16}$$

$$g_j(x) \geq 0 \quad \text{for j} = \text{m}_\text{e} + 1,......\text{m} \tag{17}$$

where '*x*' is the vector of length '*n*' design parameters, *f*(*x*) is the objective function, which returns a scalar value, and the vector function *g(x)* returns a vector of length '*m*' containing the values of the equality and inequality constraints evaluated at *x*. For the problem described in (15)-(17) the principal idea is the formulation of a Quadratic Programming (QP) sub problem based on a quadratic approximation of the Lagrangian function.

$$L(x, \lambda) = f(x) - \lambda^T g(x) \tag{18}$$

and the Jacobian of the constraints be

$$A(x)^T = \nabla g(x)^T = [\nabla g_1(x), \nabla g_2(x), ... \nabla g_m(x) \tag{19}$$

Where $A(x)^T$ is a $n \times m$ matrix

Then we obtain the QP sub problem by linearizing the non linear constraints at (x_k, λ_k)

$$\min \ \frac{1}{2} \text{d}^\text{T} \text{H}_\text{k} \text{d} + \nabla \text{f}(\text{x}_\text{k})^\text{T} \text{d} \tag{20}$$

Subject to

$$\begin{array}{ll} \nabla g_j(x_k)^T d + g_j(x_k) = 0, & \text{j} = 1,2,......\text{m} \\ \nabla g_k(x_k)^T d + g_k(x_k) \geq 0, & \text{k} = \text{m}_\text{e} + 1,....\text{m} \end{array} \tag{21}$$

Where H is the Hessian of the Lagrangian given by $\nabla^2_{xx} L(x, \lambda)$ and d can be found by solving the equation given below

$$\begin{bmatrix} H(x,\lambda) & -A(x)^T \\ A(x) & 0 \end{bmatrix} \begin{bmatrix} d_k \\ d_\lambda \end{bmatrix} = \left[-\nabla f(x_k) + A(x)^T \lambda_k \right] \tag{22}$$

The solution for the above sub problem (20) and (21) is used form a new iterate as given below

$$x_{k+1} = x_k + \alpha_{slk} + d_k \tag{23}$$

Hence the general procedure to solve a non linear-constrained optimization problem using SQP involves mainly three steps as given below
The general purpose SQP algorithm is given below:

Step 1: Choose the initial point (x_o, λ_o)

Step 2: Initialize the Hessian estimate, say $H_o = I$

Step 3: Evaluate f_o, g_o and A_o

Step 4: Begin the major iteration loop in k

Step 4.1 If termination criteria are met, then stop.

Step 4.2 Compute d_k by solving equation (22)

Step 4.3 Using d_k solve the QP sub problem (20) and (21)

Step 4.4 Using the results of step 4.3 find $x_{k+1} = x_k + \alpha_k d_k$

Step 4.5 Evaluate f_{k+1}, g_{k+1} and A_{k+1}

Step 4.6 Compute

$$\lambda_{k+1} = -\left[A_{k+1} \quad A_{k+1}^T\right]^{-1} A_{k+1} \nabla f(x_{k+1})$$

Step 4.7 Set

$$S_k = \alpha_k d_k, \qquad y_k = \nabla_x L(x_{k+1}, \lambda_{k+1}) - \nabla_x L(x_k, \lambda_{k+1})$$

Step 4.8 Obtain H_{k+1} by updating H_k using any quasi-Newton formula.

Step 5 End major iteration loop.

4. Implementation of DE-TCR and SQP for UC-ELD Problem

The DE-TCR algorithm determines the solution for UC problem and SQP determines the solution for ELD problem. Before formally presenting DE-TCR algorithm applied to UC-ELD problem, sections 4.1 to 4.8 demonstrates the various steps involved in DE-TCR and SQP algorithms with numerical examples. Section 4.9 presents DE-TCR algorithm applied to UC problem. This section 4.0 provides the step by step implementation of DE-TCR and SQP algorithm for 4 units, 8 hour UC-ELD problem. The data for the 4 units, 8 hour UC-ELD system is given in Table 1. Let the population size be 500, and the total number of generations is 1000.

4.1 Initial Generation of population for UC problem

Here the total number of generators, NG =4. Further, the total time horizon, NT =8 hrs which is also the length of chromosome. Say for example the initial representation of intelligent chromosome is as shown in Figure 3.

1 hr	2 hr	3 hr	4 hr	5 hr	6 hr	7 hr	8 hr
0.814	0.905	0.127	0.913	0.632	0.097	0.278	0.546

Figure 3: Example representation of Decision Variable in 4 units, 8 hour system

Each decision variable should be multiplied by decimal number '15' since it is a 4 unit system (the maximum 4 bit binary: '1111' – equivalent decimal representation is: '15'). The interpretation of the ON/OFF status of each unit from the intelligent chromosome is as shown Table1.
In the same way an initial chromosome pattern of size 500 is created, from which a set of 500 ON/OFF status solutions for 4 units can be obtained.

4.2 Evaluating Fitness function of UC problem

The fitness function is given in (1). It involves two modules namely (i) Fuel cost (ELD) problem (ii) Start up cost. In this section the startup cost is optimized satisfying constraints from (2) to (6) using DE-TCR. Therefore, for the ON/OFF status solution obtained from each chromosome the constraints from (2) to (6) are verified. The infeasible solutions are penalized with a high value of fitness say 1× 10 ^{100}. For the feasible solutions the fitness is calculated using module (ii) i.e.

$$\sum_{t=1}^{NT} \sum_{i=1}^{NG} SC_{i,t} (1 - U_{i,(t-1)}) U_{i,t}$$

Table 1: Interpretation of Unit Schedule form intelligent chromosome for 4 unit, 8 hour system

Decision variable value (D)	D × decimal number (15) (D1)	Unit Status representation (convert D1 into Binary equivalent)			
		Unit 1	Unit 2	Unit 3	Unit 4
0.814	12.220	1	1	0	0
0.905	13.575	1	1	0	1
0.127	1.9050	0	0	0	1
0.913	13.695	1	1	0	1
0.632	9.480	1	0	0	1
0.097	1.455	0	0	0	1
0.278	4.170	0	1	0	0
0.546	8.190	1	0	0	0

4.3 DE-TCR operators on UC problem

There are mainly two operators in DE-TCR namely mutation and adaptive crossover as explained below

4.3.1 Mutation

The mutant vector is calculated using (7). Three different 'f' values namely minimum 'f' (minf), median 'f' (medf) and maximum 'f' (maxf) is used. The typical values of triangular distribution factor of 'f' are minf=0.3, medf=0.4, and maxf=0.5. The value of 'f' for each chromosome is selected based on the procedure given below

$$\begin{aligned}
&\text{If rand} < \left[(\text{medf - minf}) \times (2/(\text{maxf - minf})) \times 0.5\right] \\
&f = \min f + \sqrt{rand \times (\max f - \min f) \times (medf - \min f)} \\
&else \\
&f = \max f - \sqrt{(1 - rand) \times (\max f - \min f) \times (\max f - medf)}
\end{aligned} \tag{24}$$

where '*rand*' is any random number between [0 to 1]. For the range of distribution factor [0.3 0.4 0.5], the value of $[(\text{medf - minf}) \times (2/(\text{maxf - minf})) \times 0.5]]$ in equation (24) is 0.5. For a chromosome, with a random number 0.3341 (say), to calculate the mutant vector using (7) the value of '*f*', using equation (24) is 0.3817. Hence depending on the random number generated, each chromosome will have its own value of '*f*'. But the triangular distribution factor for '*f*' 'is fixed and doesn't change throughout the completion of complete iterations (generations).

4.3.2 Adaptive Crossover mechanism

Let the initial triangular distribution factor for crossover be [0.2 0.5 1] (say). For this range, the value of $[(\text{medcr - mincr}) \times (2/(\text{maxcr - mincr})) \times 0.5]]$ in equation (11) is 0.6. For a chromosome, with a random number 0.1472 (say), the value of 'C_r' using (11) is 0.3880. Since the value of 'C_r' is less than 0.5 a binomial cross over is selected for that particular chromosome. In the same way for the complete chromosome set, the values of 'C_r' is calculated and the corresponding cross over is selected. Before the start of next generation, the new values of triangular distribution factor for cross over are adapted using equation (12).

4.4 Local search using SQP for UC problem

Using section 4.3.1 and 4.3.2 the new off springs (children) are created. Once when the new children are formed then to perform a local search, using (13) α_{LS} is calculated. To validate equation (14), for $rand < \alpha_{LS}$ a local search is performed.

4.5 Evaluating the off springs

For the new off springs created in section 4.4 the fitness function i.e., $SC_{i,t}(1 - U_{i,(t-1)})U_{i,t}$ is evaluated.

4.6 Population refreshment for UC problem

In this module, a fraction of population is reinitialized with a new search space bounds to obtain population refreshment. Let us consider the value of the threshold of IRQ, $\gamma_{\text{var}} = 2$ (say). For the complete population or chromosome set the interquartile range (IQRrange) is found i.e. the difference between the 75th and 25th percentiles of population. This value is compared as shown below

$$\text{If IQR} < \left(\frac{\text{x}^*_{\text{upper}} - x^*_{lower}}{\gamma_{\text{var}}} \right)$$

$$x_{upper} = x^{median} + \gamma_{\text{var}} \times (\text{x}^*_{\text{upper}} - x^*_{lower})$$

$$x_{lower} = x^{median} - \gamma_{\text{var}} \times (\text{x}^*_{\text{upper}} - x^*_{lower}) \tag{25}$$

Where x^*_{upper} and x^*_{lower} are the bounds of chromosomes since the last population refreshments. $x_{lower}, x^{median}, x_{upper}$ be the lower, median and upper bounds of chromosomes at current generation.

After the above process, the actual bounds of the decision variable is checked, if violated the values of violating bound is reinitialized.

4.7 Check for Convergence for UC problem

Once when the new populations are generated the fitness value is evaluated and the convergence criteria i.e. maximum generations of 1000 are reached. If this condition fails then for the current population the DE-TCR operators are applied and the iterative process continues until the convergence criteria is met.

4.8 SQP for ELD problem

Once when the complete process of DE-TCR is over, then the final population gives the best optimal unit schedule. For this schedule the SQP algorithm as explained in section 3.2.5 is performed to minimize the objective $\sum_{i=1}^{NG} FC_i U_i$ hence the optimal generation schedule for the given optimal unit schedule is obtained.

4.9 Algorithm and flow chart for UC-ELD using DE-TCR and SQP problem

The algorithm for UC-DE-TCR is given below:

Step1: Read the population size, size and length of decision variables along with unit commitment data etc.

Step 2: Initialize population within the search space.

Step 3: Increase the counter for number of generations.

Step4: For each hour, from the information obtained from every chromosome, make the corresponding generators ON and OFF respectively and obtain a set of solutions for UC equal to the size of population.

Step 5: Check for feasibility of solution and UC constraints. For the set of chromosomes satisfying the constraints and meeting solution feasibility compute the fitness using $\sum_{t=1}^{NT}\sum_{i=1}^{NG} SC_{i,t}(1-U_{i,(t-1)})U_{i,t}$. The remaining chromosomes are penalized with high fitness.

Step 6: Perform cross over and mutation operation from triangular distribution factors.

Step 7: Perform a local search using SQP for the every child or offspring. Evaluate fitness using (1), for each individual. Ensure elitism by comparing the fitness of child and parent and replace accordingly.

Step 8: Record the number of success and reset the cumulative number and recalculate the triangular distribution factor for 'C_r'. Check for population refreshment.

Step 9: Check for convergence or maximum generations reached. If YES then GO TO *Step 10* else GO TO *Step 3*. *Step 10:* For the optimal unit schedule obtained in step 9, run SQP algorithm as explained in sec 3.2.5 to

minimize $\sum_{i=1}^{NG} FC_i U_i$ for ELD problem and hence obtain the optimal generation schedule.

Step 11: Print the optimal values of decision variables and STOP.

The flow chart for the UC-ELD problem using DE-TCR and SQP is as shown in Figure 4.

5. Numerical Results and Discussion

The application of DE-TCR and SQP for UC-ELD is presented and the results are compared against the known reported methods. DE-TCR, SQP, UC and ELD programs are executed in MATLAB R2009b. Two test cases are considered. *Case 1:* Standard 4 units, 8 hour system – Table 2, *Case 2:* Standard 10 units, 24 hour system - Table 5. The parameter value in DE-TCR algorithm is population: 500, maximum generations: 1000, Triangular distribution for the differentiation factor for '*f*' and 'C_r' are [0.3 0.4 0.5] and [0.2 0.5 1.0] respectively. For SQP the default settings of MATLAB R2009b are considered.

Case 1: 4 Units, 8 hour Test system

The data for the case 1 test system is given in Table 2. DE-TCR and SQP is applied for this system and the results obtained are shown in Table 3. It is evident from Table 3. that the optimal production cost for complete 8 hour demand is 73796.7 $ and the optimal Start up cost is 520.02 $. Therefore the optimal total cost for the complete schedule using DE-TCR and SQP is 74316.72$. The comparison of result obtained using the proposed method against the other reported methods is shown in Table 4. From Table 4. it is evident that the proposed method finds better optimal value when compared to other methods.

Case 2: 10 Units, 24 hour Test system

The data for the case 2 test system is given in Table 5. DE-TCR and SQP is applied for this system and the results obtained are shown in Table 6. It is evident from Table 6. that the optimal production cost for complete 24 hour demand is 555508.9 $ and the optimal Start up cost is 8240.0 $. Therefore the optimal total cost for the complete schedule using DE-TCR and SQP is 563748.9$. The comparison of result obtained using the proposed method against the other reported methods is shown in Table 7. The comparison of result obtained using the proposed method against the other reported methods is shown in Table 7. From Table 7, it is evident that the proposed method finds better optimal value when compared to other methods.

6. Conclusions

This paper presents a novel method namely DE-TCR and SQP for UC-ELD problem. The salient features of the proposed DE-TCR are:

(1) Adaptive Crossover in DE, which is able to interlink the cross over probability in conjunction

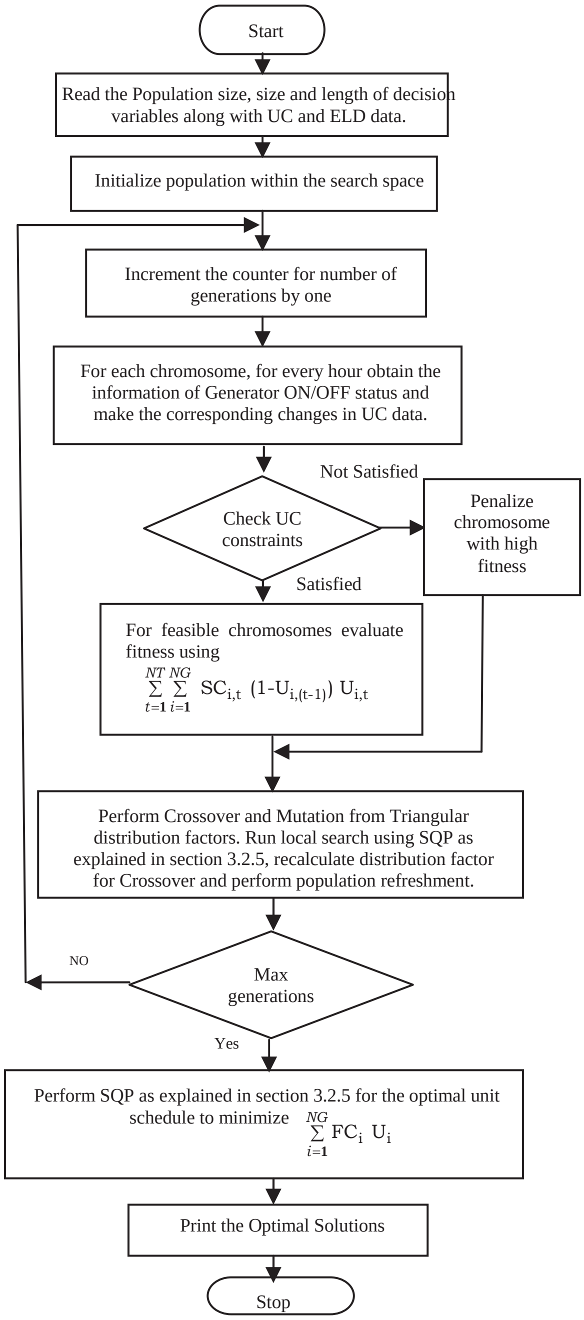

Figure 4: Flow chart for UC-ELD using DE-TCR and SQP algorithm

With the non-separable and decision variable dependency of UC problems.

(2) Local search in each chromosome using SQP, which has proved in improving the performance of the classical DE algorithm and

(3) Intelligent chromosome representation, which is capable of searching a large space for the purpose of obtaining global optimal solution. The proposed algorithm is tested with standard 4 units, 8 hour and 10 units, 24 hour test systems. Results indicate that the proposed method finds better optimal solution when compared to the conventional known methods reported in the literature.

Table 2: Case 1: Test system Data

Units	P_{min} (MW)	P_{max} (MW)	Cold Cost ($)	MUT (Hrs)	MDT (Hrs)	Initial State (Hrs)	Hot cost ($)	Cold Start (hrs)	Cost Coefficients		
									a	B	C
1	25	80	350	4	2	-5	150	4	213	20.74	0.0018
2	60	250	400	5	3	8	170	5	585.62	16.95	0.0042
3	75	300	1100	5	4	8	500	5	648.74	16.8	0.0021
4	20	60	0.02	1	1	-6	0	0	252	23.6	0.0034
Hours	1	2	3	4	5	6	7	8			
Demand	450	550	600	540	400	280	290	500			

Table 3: Case 1: UC-ELD solution using DE-TCR and SQP

Unit/ Hours	Load (MW)	G1 (MW)	G2 (MW)	G3 (MW)	G4 (MW)	Production Cost ($)	StartUp cost ($)	Cummulative Total Cost ($)
1	450	0	150	300	0	9208.4	0	9208.4
2	530	0	230	300	0	10648.4	0	19856.8
3	600	50	250	300	0	12265.4	350	32472.2
4	540	25	215	300	0	11113.4	0	43585.6
5	400	80	0	300	20	8534.1	0.02	52119.72
6	280	25	0	255	0	5872	0	57991.72
7	290	25	0	265	0	6046.6	0	64038.32
8	500	0	200	300	0	10108.4	170	74316.72
					Total Cost	**73796.7**	**520.02**	**74316.72**

Table 4: Case 1: Comparison of results with other methods

Solution Methods	Total Cost ($)
LR [38]	74808
LR-PSO [38]	75231.9
FL [38]	74683.6
ACO [38]	74520.34
DE-TCR and SQP (Proposed)	**74316.72**

Table 5: Case 2: Test system data

Units	P_{min} (MW)	P_{max} (MW)	Cold Cost ($)	MUT (Hrs)	MDT (Hrs)	Initial State (Hrs)	Hot cost ($)	Cold Start (hrs)	Cost Coefficients		
									a	b	C
1	150	455	9000	8	8	8	4500	5	1000	16.19	0.00048
2	150	455	10000	8	8	8	5000	5	970	17.26	0.00031
3	20	130	1100	5	5	-5	550	4	700	16.6	0.002
4	20	130	1120	5	5	-5	560	4	680	16.5	0.00211
5	25	162	1800	6	6	-6	900	4	450	19.7	0.00398
6	20	80	340	3	3	-3	170	2	370	22.26	0.00712
7	25	85	520	3	3	-3	260	2	480	27.74	0.00079
8	10	55	60	1	1	-1	30	0	660	25.92	0.00413
9	10	55	60	1	1	-1	30	0	665	27.27	0.00222
10	10	55	60	1	1	-1	30	0	670	27.79	0.00173
Hours	1	2	3	4	5	6	7	8	9	10	11
Demand	700	750	850	950	1000	1100	1150	1200	1300	1400	1450
Hours	12	13	14	15	16	17	18	19	20	21	22
Demand	1500	1400	1300	1200	1050	1000	1100	1200	1400	1300	1100
Hours	23	24									
Demand	900	800									

Table 6: Case 2: UC-ELD solution using DE-TCR and SQP

Unit / Hrs	Load (MW)	G1 (MW)	G2 (MW)	G3 (MW)	G4 (MW)	G5 (MW)	G6 (MW)	G7 (MW)	G8 (MW)	G9 (MW)	G10 (MW)	Production Cost	Startup cost	Cummulative Total Cost
1	700	455	245	0	0	0	0	0	0	0	0	13683.1	0	13683.1
2	750	455	295	0	0	0	0	0	0	0	0	14554.5	0	28237.6
3	850	455	395	0	0	0	0	0	0	0	0	16301.9	0	44539.5
4	950	455	455	0	0	0	0	0	30	0	10	19742.7	120	64402.2
5	1000	455	405	130	0	0	0	0	0	0	10	20316.8	1100	85819
6	1100	455	455	130	0	0	60	0	0	0	0	21976.3	340	108135.3
7	1150	455	425	130	130	0	0	0	0	10	0	23517.7	1180	132833
8	1200	455	440	130	130	0	20	25	0	0	0	24834.7	690	158357.7
9	1300	455	455	130	130	105	0	25	0	0	0	26842.1	1800	186999.8
10	1400	455	455	130	130	162	43	25	0	0	0	29365.9	170	216535.7
11	1450	455	455	130	130	162	80	38	0	0	0	30583.2	0	247118.9
12	1500	455	455	130	130	162	80	70	0	0	17.7	32644.4	60	279823.3
13	1400	455	455	130	130	162	48	0	0	10	10	30192.5	60	310075.8
14	1300	455	455	130	130	120	0	0	0	10	0	26915	0	336990.8
15	1200	455	455	0	130	125	0	25	10	0	0	25282.3	320	362593.1
16	1050	455	455	0	130	0	0	0	0	10	0	21151.9	60	383805
17	1000	455	380	0	130	0	0	25	10	0	0	20933.7	320	405058.7
18	1100	455	455	0	130	60	0	0	0	0	0	21860.3	900	427819
19	1200	455	440	130	130	25	20	0	0	0	0	24605.7	890	453314.7
20	1400	455	455	130	130	162	68	0	0	0	0	28762.2	0	482076.9
21	1300	455	455	130	130	130	0	0	0	0	0	26184	0	508260.9
22	1100	455	455	0	130	0	50	0	0	10	0	22652.7	230	531143.6
23	900	455	455	0	0	0	0	0	0	0	0	17177.9	0	548321.5
24	800	455	345	0	0	0	0	0	0	0	0	15427.4	0	563748.9
Total Cost												**555508.9**	**8240**	**563748.9**

Table 7: Case 2: Comparison of results with other methods

Solution Methods	Total Cost ($)
LR [23]	565,825
GA[23]	565,825
EP [23]	564,551
SA [23]	565828
IPSO [23]	563954
NBACO [23]	563977
ICGA [29]	566404
BF [29]	564842.0
HPSO [29]	563942.3
ICA [29]	563937.7
DE-TCR and SQP (Proposed)	**563748.9**

Nomenclature

NT	Total schedule period in hours
NG	Number of generating units in the plant
i	Index of units (i=1,2,3,…..)
t	Index of time (t=1,2,…….NT)
$FC_{i,t}$	Fuel cost of the ith unit at time t
$P_{i,t}$	Amount real power generated in the ith unit
$SC_{i,t}$	Generation startup cost of ith unit at time t
$U_{i,t}$	Unit ON/OFF status of ith unit (=1, if the unit is ON; =0, if the unit is OFF)
PD_t	Real power demand at given time t
$T_{i,t}^{on}$	Total time for which the ith unit is turned ON at time t.

$T_{i,t}^{off}$ Total time for which the i^{th} unit is turned OFF at time t
MUT_i Minimum up time for the i^{th} unit
MDT_i Minimum down time for the i^{th} unit
a_i,b_i,c_i Fuel cost coefficients

7. References

[1] A.J. Wood and B.F. Wollenberg: Power Generation, Operation and Control, John Wiley & Sons Inc., New York, second edition, chapter 5, pp. 131-169, 2006.

[2] N.P. Padhy: Unit commitment-A bibliographical survey, IEEE Trans. Power Syst., Vol. 19 No. 2, pp. 1196-2005, May 2004.

[3] K. Hara, M. Kimura and N. Honda: A method for planning economic unit commitment and maintenance of thermal power systems, IEEE Trans. Power Apparatus and Systems, Vol. PAS-85 No. 5, pp. 427–436, May 1966.

[4] F.N. Lee: Short-term thermal unit commitment-a new method, IEEE Trans. Power Syst., Vol. 3 No. 2, pp. 421–428, May 1988.

[5] R.M. Burns and C.A. Gibson: Optimization of priority lists for a unit commitment program, Proc. IEEE Power Engineering Society Summer Meeting, Paper A-75-453-1, 1975.

[6] W.L. Snyder Jr., H.D. Powell Jr. and J.C. Rayburn: Dynamic-programming approach to unit commitment, IEEE Trans. Power Syst., Vol. 2 No. 2, pp. 339–347, May 1987.

[7] Z. Ouyang and S.M. Shahidehpour: An intelligent dynamic programming for unit commitment application, IEEE Trans. Power Syst., Vol. 6(3), pp. 1203-1209, August 1991.

[8] T.S. Dillon, K.W. Edwin, H.D. Kochs and R.J. Taud: Integer programming approach to the problem of optimal unit commitment with probabilistic reserve determination, IEEE Trans. Power App. Syst., Vol. PAS-97 No. 6, pp. 2154–2166, November/December 1978.

[9] J.A. Muckstadt and R.C. Wilson: An application of mixed-integer programming duality to scheduling thermal generating systems, IEEE TRANS. POWER APPARATUS AND SYSTEMS, Vol. PAS-87 No. 12, pp. 1968-1978, December 1968.

[10] A.I. Cohen and M. Yoshimura: A Branch-and-Bound Algorithm for Unit Commitment, IEEE Trans on Power Apparatus and Syst, Vol. PAS-102 No. 2, pp. 444-451, February 1983.

[11] F. Zhuang and F.D. Galiana: Towards a more rigorous and practical unit commitment by Lagrangian relaxation, IEEE Trans. Power Syst., Vol. 3 No. 2, pp. 763-770, May 1988.

[12] P.T. Boggs and J.W. Tolle: Sequential Quadratic Programming, Acta Numer., Cambridge University Press, Cambridge, UK, Vol. 4, pp. 1–51, 1995.

[13] A.H. Mantawy, Y.L. Abdel-Magid, and S.Z. Selim: Unit commitment by Tabu search, IEE Proc Gener Transm Distrib, Vol. 145 No. 1, pp. 56–64, January 1998.

[14] D.N. Simopoulos, S.D. Kavatza and C.D. Vournas: Unit commitment by an enhanced simulated annealing algorithm, IEEE Trans Power Syst, Vol. 21 No. 1, pp. 68-76, February 2006.

[15] S. Li, S.M. Shahidehpour and C. Wang: Promoting the application of expert systems in short-term unit commitment, IEEE Trans. Power Syst., Vol. 8 No. 1, pp. 286–292, March 1993.

[16] S. Saneifard, N.R. Prasad and H.A. Smolleck: A fuzzy logic approach to unit commitment, IEEE Trans. Power Syst., Vol. 12 No. 2, pp. 988–995, May 1997.

[17] H. Sasaki, M. Watanabe, J. Kubokawa, N. Yorino and R. Yokoyama: A solution method of unit commitment by artificial neural network, in Proc. IEEE Power Eng. Soc. Summer Meeting, 1991.

[18] D.C. Walters and G.B. Sheble: Genetic algorithm solution of economic dispatch with valve point loading, IEEE Trans. Power Syst., Vol. 8 No. 3, pp. 1325–1332, August 1993.

[19] S.A. Kazarlis, A.G. Bakirtzis and V. Petridis: A genetic algorithm solution to the unit commitment problem, IEEE Trans. Power Syst., Vol. 11 No. 1, pp. 83-92, February 1996.

[20] K.A. Juste, H. Kita, E. Tanaka, and J. Hasegawa: An evolutionary programming solution to the unit commitment problem, IEEE Trans. Power Syst., Vol. 14 No. 4, pp. 1452–1459, November 1999.

[21] N. Sinha, R. Chakrabarti, and P.K. Chattopadhyay: Evolutionary programming technique for economic load dispatch, IEEE Trans. Evol. Comput., Vol. 7 No. 1, pp. 83–94, February 2003.

[22] S. Chusanapiputt, D. Nualhong and S. Phoomvuthisarn: Relativity Pheromone Updating Strategy in Ant Colony Optimization for Constrained Unit Commitment Problem, IEEE International conference on Power System Technology, PowerCon 2006, Chongqing, pp. 1-8, October 2006.

[23] S.H. Jang, J.H. Roh, W. Kim, T. Sherpa, J.H. Kim and J.B. Park: A Novel Binary Ant Colony Optimization: Application to the Unit Commitment Problem of Power Systems, Journal of Electrical Engineering and Technology, Korea, Vol. 6 No. 2, pp. 174-181, March 2011.

[24] B. Zhao, C.X. Guo, B.R. Bai and Y.J. Cao: An improved particle swarm optimization algorithm for unit commitment, Int. J. Elect. Power Energy Syst., 28, pp. 482-492, September 2006.

[25] S. Patra, S.K. Goswami and B. Goswami: Differential Evolution Algorithm for solving unit commitment with ramp constraints, Electric Power Components and Systems, Vol. 36 No. 8, pp. 771-787, June 2008.

[26] A. Keles: Binary differential evolution for the unit commitment problem, ACM Press, New York, New York, USA, pp. 2765-2768, 2007.

[27] R. Balamurugan, and S. Subramanian: Self-Adaptive Differential Evolution Based Power Economic Dispatch of Generators with Valve-Point Effects and Multiple Fuel Options, World Academy of Science, Engineering and Technology, Vol. 27, pp. 466-473, 2007.

[28] M. Eslamian, S.H. Hosseinian and B. Vahidi: Bacterial Foraging-Based Solution to the Unit-Commitment problem, IEEE Trans. Power Syst., Vol. 24 No. 3, pp. 1478–1488, August 2009.

[29] M. Moghimi Hadji and B. Vahidi: A Solution to the Unit Commitment Problem Using Imperialistic Competition Algorithm, IEEE Trans. Power Syst., Vol. 27, No. 1, pp. 117–124, February 2012.

[30] R. Jahani, H. Chahkandi Nejad, A.H. Araskalaei and M. Hajinasiri: A Solution to The Unit Commitment Problem Using Hybrid Genetic and particle swarm optimization Algorithms, Australian Journal of Basic and Applied Sciences, Vol. 5 No. 5, pp. 628-634, 2011.

[31] P. Surekha, N. Archana and S. Sumathi: Unit Commitment and Economic Load Dispatch using Self Adaptive Differential Evolution, WSEAS Transactions on Power Systems, Vol. 7 No. 4, October 2012.

[32] K. Chandrasekaran and Sishaj P. Simon: Multi-objective scheduling problem: Hybrid approach using fuzzy assisted cuckoo search algorithm, Elsevier: Swarm and Evolutionary Computation, Vol. 5, pp. 1–16, February 2012.

[33] L. dos Santos Coelho and V.C. Mariani: Combining of Chaotic Differential Evolution and Quadratic Programming for Economic Dispatch Optimization With Valve-Point Effect, IEEE Trans. Power Syst., Vol. 21 No. 2, pp. 989–996, May 2006.

[34] G. Reynoso-Meza, J. Sanchis, X. Blasco and J M. Herrero: Hybrid DE Algorithm With Adaptive Crossover Operator For Solving Real-World Numerical Optimization Problems, IEEE congress on Evolutionary Computation, 2011.

[35] R. Storn and K. Price: Differential evolution-A simple and efficient heuristic for global optimization over continuous spaces, J. Glob. Optim., Vol. 11 No. 4, pp. 341 – 359, December 1997.

[36] P.E. Gill, W. Murray, and M.H. Wright: Practical Optimization, Academic Press, London, London, U.K., 1981.

[37] N. Noman and H. Iba: Accelerating differential evolution using an adaptive local search, IEEE transactions on Evolutionary Computation, Vol. 12 No. 1, pp. 107 –125, February 2008.

[38] A. Ameli, A. Safari and H.A. Shayanfar: Modified Ant Colony Optimization technique for solving Unit commitment problem, International Journal on Technical and Physical Problems of Engineering, Vol. 3 No.4, pp. 29-35, December 2011.

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Artificial Intelligence and Machine Learning Journal, ISSN 1687-4846, Volume 14, Issue 1, Delaware-USA, August 2014

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E-assessment: Ontological Model for Personalizing Assessment Activities

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Abstract

This paper focuses on a proposal for e-assessment, its goal is to propose an alternative solution to the problem of school failure, attending to diversity from the perspective of the evaluation. The proposal for e-assessment relies an ontological model for personalizing assessment activities. In this paper we presented the design of three ontologies that can represent the thinking style of students, the assessment activities and the learning path, this ontologies will allow to make a recommendation of different type of activities to develop the students skills necessary skills to cover course objectives. The model is the result of fieldwork conducted with engineering students from the Universidad Autónoma Metropolitana-Atzcapotzalco.

Keywords: *assessment, research, technology, learning design, ontological model.*

1. Introduction

The evident diversity of the academic community, presents a challenge for the new educational paradigm, requires the adoption of a model that allows access to knowledge and learning to all students, which implies to recognize the differences between individuals. This paper presents an ontological model whose purpose is to recommend the personalized assessment activities for engineering students of Universidad Autónoma Metropolitana Azcapotzalco, according to their learning profile in a virtual learning environment.

The educational models in Mexico do not respond to the problem of school failure, that includes academic lag, reprobation and low terminal efficiency. However, this problem is not restricted to Mexico, and can be considered as an internationally relevant problem, as can be seen in the high number of articles, publications and books that analyze it [1]. Thus, we believe that it is necessary to propose new alternatives to experiment and to find better solutions to the previously mentioned problems.

In this sense, we consider that a new model must take advantage of the new communication and information technologies to overcome educational problems. Besides, we include ontological models to add intelligence to the selection mechanisms of e-assessment in order to attend student diversity. In this paper we propose an ontological model that designs personalized assessment activities and have an e-assessment, based on field work undertaken during two years, with the goal of improving school efficiency.

The Ontological Model for Personalized Assessment Activities (OMPAA) integrates three ontologies to represent the thinking style of students, the assessment activities and the learning path. From the skills that students must develop to complete the course, the ontological model sets the path to personalized assessment activities. In this paper, we consider personalization as an individuation process and subject realization. The personalization as psychoanalytic theories implies differentiation and individuation [2].

The ontologies representation is done with the Web Ontology Language (OWL) [3], latest standard language proposed by the W3C for representing ontologies on the Web, and its implementation is done with the tool Protégé [4].

A detailed breakdown of the structure of the rest of the paper is as follows. Section 2 presents the assessment concept. Section three contains the assessment activities

and their relationship with the thinking style. The fourth section presents the review about ontologies related with education. The fifth section presents the proposed ontological model. The sixth section contains the experimental work and results. Finally the conclusion are presented in section seven.

2. The assessment

The term "assessment" is often used synonymously with proof, exams, test. The assessment is a process or a set of activities programmed of reflection about the action, supported by systematic procedures for collecting, analyzing and interpreting information in order to make informed and communicable judgments, to make recommendations, to take decisions, to review actions, to present and to improve future actions [5].

Assessment is a process that integrates multiple activities that allow students to practice concepts, to understand and to associate them with their prior knowledge. At the same time, the assessment is an indicator that allows the teacher to give feedback to the student, and to adjust the strategy being implemented in the student personalized learning activity.

3. Assessment activities and their relationship with the thinking style

Metacognition can be defined as the awareness degree or knowledge that individual possesses about their thinking forms, considering cognitive processes and events; the structures and the ability to control these processes (organize it, review it and modify it) based on learning outcomes [6,7,8].

To attend the thinking style, Cognitive Neuroscience theories were evaluated [9,10,11]. Sperry's research confirms the specialization of the cerebral hemispheres. The right hemisphere is specialized in simultaneous process, integrates and organizes information globally, focuses on relationships, is holistic [10]. While Verlee suggests that the difference between the two brain hemispheres, is its style of processing information [12]. MacLean presents a different view of how the brain works, complementing Sperry investigations. MacLean's conceptualization suggests that the brain consists of three interconnected components: the reptilian brain, the limbic system and the neocortex, responsible for controlling human behavior [9]. Ned Herrmann, from studies of Sperry cerebral dominance and the MacLean's triune brain theory, as well as on the results of their own investigations, using biofeedback equipment (bio-feedback) and electroencephalography, rethinks the problem of cerebral dominance (Ruiz Bolívar and Cols., 1994) cited in [13].

For purposes of this work we selected the total brain theory of Herrmann Ned, his model integrates the neocortex (right and left hemispheres) with limbic system, obtaining four quadrants of this intersection, this quadrants determine different styles of information processing in individuals [11]. Based on this theory, we classified assessment activities that can be programmed in a course in four sets, as shown in Figure 1.

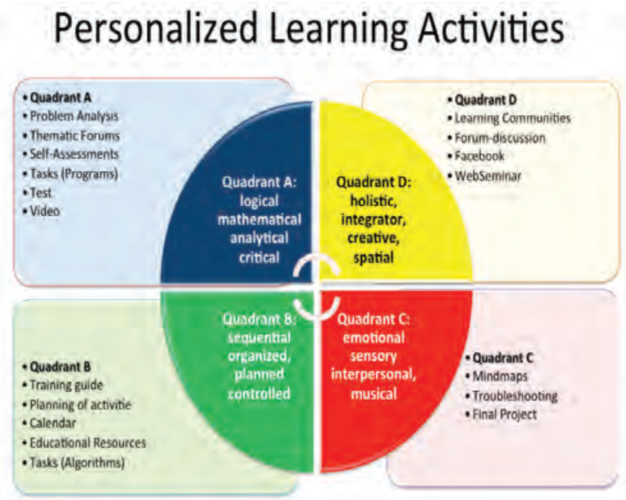

Figure 1. Assessment activities and whole brain theory of Herrmann Ned

The whole brain theory divides the brain into four quadrants. Quadrant A (Logical) focuses on responding what?, it's based on facts, it's analytical, logical, rational; Quadrant B (Process) seeks explanation of how?, it's organized, sequential, conservative and orderly; Quadrant C (Relational) responds to who?, it's interpersonal, emotional, intuitive, its interrelation with others is critical, so quadrant C prefers activities that are related with others, and finally the Quadrant D (Creative), answers the why? of things, it's inclusive, visionary, risk-taker, it's excited to create and invent. The A and B quadrants are related to the left hemisphere of the brain, while the C and D quadrants are associated with the right hemisphere.

Classifying the various assessment activities according to the characteristics of each quadrant, is the first step to customize the assessment to attend the diversity of students' thinking. For quadrant A we recommend assessment tools such as desk research, case analysis, written examinations, among others. While for quadrant B is recommendable to use concept maps, summary tables, tests, among others. For quadrant C we propose evaluation activities carried out on computer, for example the use of social networks is highly recommended, videoconferencing, discussion, prototype design and its representation. Finally, for quadrant D is recommendable to apply fieldwork, problem solving from knowledge acquired, activities that implement what they have learned as prototyping, project development, among others.

The classification of personalized assessment activities using the student's thinking style is an easy task, however, is a complex task to perform manually by the teacher, therefore, we propose an ontological model that automates this activity and recommends to the teacher a set of activities that should be scheduled to.

4. Related work

This section is divided in 2 subsections, the first part contains a review of a set of ontology repositories and the second describes the tools used to perform ortologies in this work.

4.1. Related ontologies

In order to validate the use of ontologies or existing metadata, we review the existing ontologies. We validated the following ontology repositories:

1. http://www.ksl.stanford.edu/software/ontolingua
2. http://www.daml.org/ontologies/
3. http://www.dmoz.org/Reference/Education/
4. http://www.unspsc.org

30,773 related ontologies with the knowledge domain of education were located, of which: a) 663 related to online learning, b) 58 related to educators and c) 1,246 focused on the administrative or management institution. However some related ontologies with learning profile and personalized assessment through a learning path was not found. We listed below a set of ontologies closely related to educational field:

- Ontology
  http://www.cs.umd.edu/projects/plus/DAML/onts/univ1.0.daml
  This ontology describes the activities that take place within a university, considers the entire management and research environment. In the part of teaching is limited to courses offered, however it is not specialize in assessment and learning profiles.
  It can be accessed from:
  http://www.daml.org/ontologies/63.
  The link to access the technical information is:
  http://www.cs.umd.edu/projects/plus/DAML/onts/univ1.0.daml.

- Ontology
  http://www.ksl.stanford.edu/projects/DAML/ksl-daml-instances.daml
  This ontology focuses on people, projects, articles and academic organization. It does not properly consider the issues associated with assessment and learning profiles.
  It can be accessed from:
  http://www.ksl.stanford.edu/projects/DAML/ksl-daml-instances.daml.
  The link to read the technical description of it is:
  http://www.ksl.stanford.edu/projects/DAML/ksl-daml-descr.daml.

- Ontology
  http://www.ksl.stanford.edu/projects/DAML/ksl-daml-desc.daml
  This ontology has as topics of interest projects, articles, research programs.
  http://www.ksl.stanford.edu/projects/DAML/ksl-daml-instances.daml.
  To access the technical information of ontology we refer the reader to the link:
  http://www.ksl.stanford.edu/projects/DAML/ksl-daml-desc.daml.

- Ontology
  http://www.aktors.org/ontology/portal
  This ontology describes a computer science academy scene, considering departments, people, projects, publications, research.
  To access the technical information we refer the reader to the link:
  http://www.aktors.org/ontology/portal.

Hayashi, Bourdeau and Mizoguchi (2009) presented a model called OMNIBUS ontology, which organizes learning and instructional theories to construct learning scenarios [14]. Although this ontology is focused in the construction of learning scenarios with a selection of appropriate learning objects to different learning states, does not consider three fundamental points that must be present during the individual learning: 1) motivation, 2) individual learning preferences and 3) cognitive skills to be developed during their learning experience.

After an extensive revision, we concluded that there are not ontologies directly related with the domain knowledge of the learning profile and the personalized assessment.

4.2. Tools used to build ontologies

To perform the ontologies described in this work, we used Web Ontology Language (OWL) which is an intended to provide a language that can be used to describe classes and relations between them that are inherent in Web documents and applications [3]. OWL can be used to 1) Formalize a domain by defining classes and properties of those classes, and 2) Define individuals and assert properties about them.

The OWL language provides three increasingly expressive sublanguages designed to be used by specific communities of implementers and users. A) ***OWL Lite*** supports those users who primarily need a classification hierarchy and simple constraint features. B) ***OWL DL*** supports those users who want the maximum expressiveness without losing computational completeness. C) ***OWL Full*** is meant for users who want maximum expressiveness and the syntactic freedom of RDF with no computational guarantees.

Each of these sublanguages is an extension of its simpler predecessor [3].

Ontologies in this work were built using Protégé which is a free, open-source ontology editor and framework for building intelligent systems. Protégé is supported by a strong community of academic, government, and corporate users, who use Protégé to build knowledge-based solutions in areas as diverse as biomedicine, e-commerce, and organizational modeling. Protégé's plug-in architecture can be adapted to build both simple and complex ontology-based applications. Developers can integrate the output of Protégé with rule systems or other problem solvers to construct a wide range of intelligent systems [4].

5. The proposed ontological model

To achieve the strategic learning in education mediated by ICT is necessary to consider aspects such as diversity and evaluation, which are key factors in strategic learning.

The work developed by Silva [15] proposed that the goal of the architecture of Strategic Learning Meta-Model (SLM) is to improve student performance, to make strategic learners, self-regulated and self-reflective, encouraging learning through an educational environment that integrates a psycho-pedagogical model, an ontological model and emerging technologies that enable ubiquity. The strategic learning meta-model provides an architecture consisting of three layers: the reactive layer, intelligent layer and the infrastructure layer [15].

The ontological model is the intelligence of the system, and is composed of five ontologies, which are: courses, assessment activities, profiles, students and learning path.

Creating ontologies is one of the artificial intelligence models that organize knowledge in standard form, with the purpose of categorize the information in such a way that it can be processed by computers.

The term ontology is adopted by artificial intelligence as a mechanism to share and reuse knowledge. According to Guarino [16,17] an ontology is an artefact, consisting of a specific vocabulary that describes a knowledge domain, integrating a set of rules that explain the vocabulary. While McGuinness defined an ontology as the formal explicit description of concepts in a domain, including its properties and existing constraints [18].

Although there are many different definitions of ontology, one of the most accepted is of Thomas Gruber: "a formal explicit specification of a shared conceptualization" [19].

For each of the developed ontologies was necessary to identify classes and key concepts, define the class hierarchy, and then is necessary to describe the properties and relationships between classes. It must be considered that all subclasses of a class inherit the properties of that class, so that a property must be defined in most general class possible. In figure 2 the properties and relationships of each class of the 5 ontologies are presented.

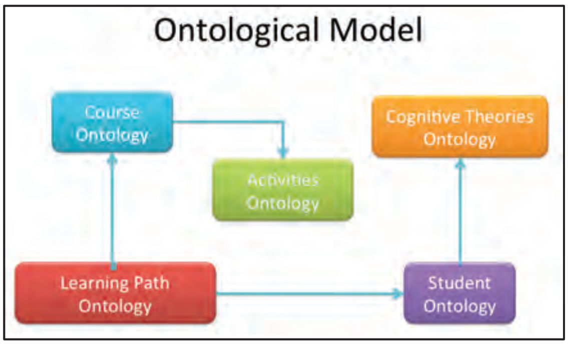

Figure 2. Relationships between classes of ontologies.

The set of ontologies are used to personalize the student learning path from her/his learning profile. An applicative case was defined in a programming structured course with engineering students at the Universidad Autónoma Metropolitana-Azcapotzalco (UAM-A).

The Ontological Model for Personalized Assessment Activities presented here provides the description of this 3 ontologies: learning path, student and the assessment activities. The design of these three ontologies were based of Noy & McGuiness [20] methodology, and OntoDesign Graphics for graphical representation. OntoDesign Graphics is used to standardize the graphical design of an ontology. In this paper we present the design of the three previously mentioned ontologies using the Protége-OWL editor and in OWL format.

5.1. Learning path ontology

Learning path ontology is constituted by two classes: InstructionalPlan and LearningPath and as shown in figure 3. These classes are populated by inference rules that evaluate the information associated with the student profile and the skills that students must develop to complete the course. Inference rules build the student's personalized learning path, considering assessment activities that motivate students as they are associated with your learning profile and assessment activities that are necessary for students to develop desirable skills in the course.

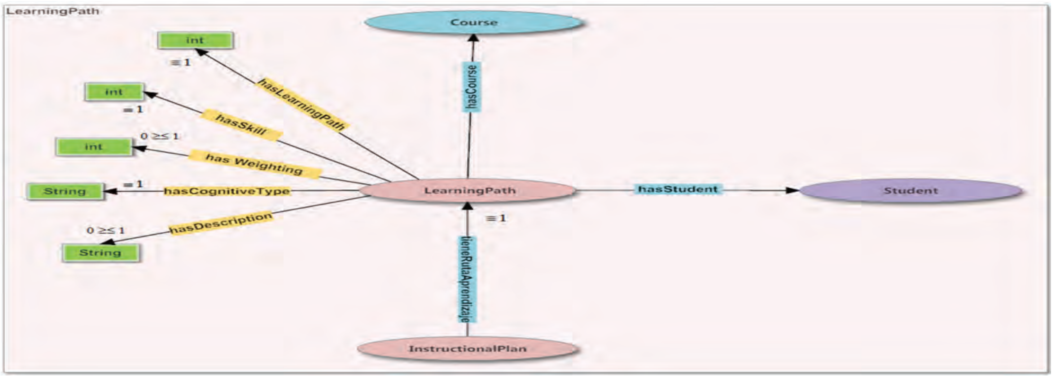

Figure 3 Learning Path Ontology

5.2. Student learning profile ontology

The ontology of student learning profile integrates 2 classes: *Student* and *LearningProfile*, as shown in figure 4. The ontology model of learning profile allows to classify the student, with the purpose of customize teaching and attend the thinking and learning diversity [21].

5.3. Assessment activities ontology (personalization of learning activities)

The ontology of assessment activities model integrates three classes: *Activity*, *CogntiveSkill* and *Tool* (as shown in figure 5). The Activity class includes several assessment activities, each activity has weights associated to the cognitive skills that can be developed in students and register in CognitiveSkill class. The Tool class stores technology tools that can be used for carrying out assessment activities.

6. Experimental work and results

The case study was defined on two courses for engineering students of the UAM-A. The Structured programming course and the numerical methods in engineering course. Experiments were conducted for 2 years, with a total of 7 experiments in which personalized learning activities according to the theory of total brain, as indicated in figure 1.

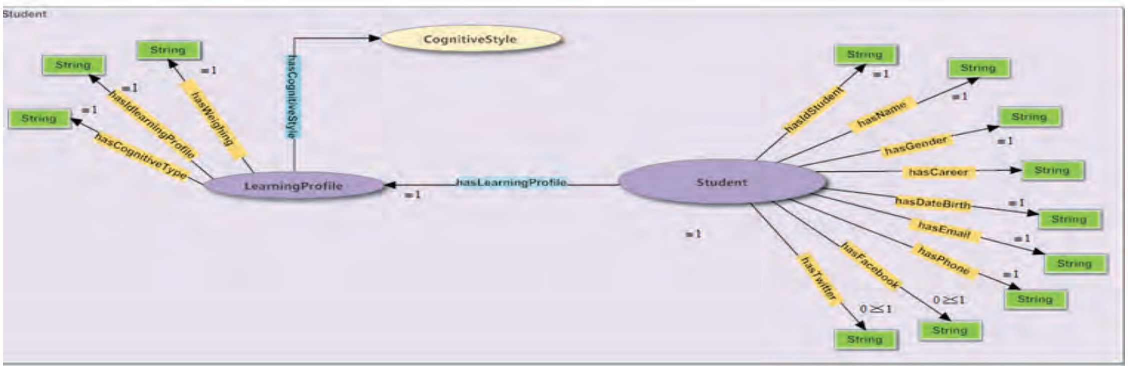

Figure 4 Student Learning Ontology

6.1. Methodology

The methodology involves the application of the student test that determines his/her style of thinking. It sets the course and develop the skills required by the student. The student's thinking style is used to create the personalized learning activities.

Upon completion of the course the student is assessed in personalized interviews, as well as check their progress through the thinking style questionnaire.

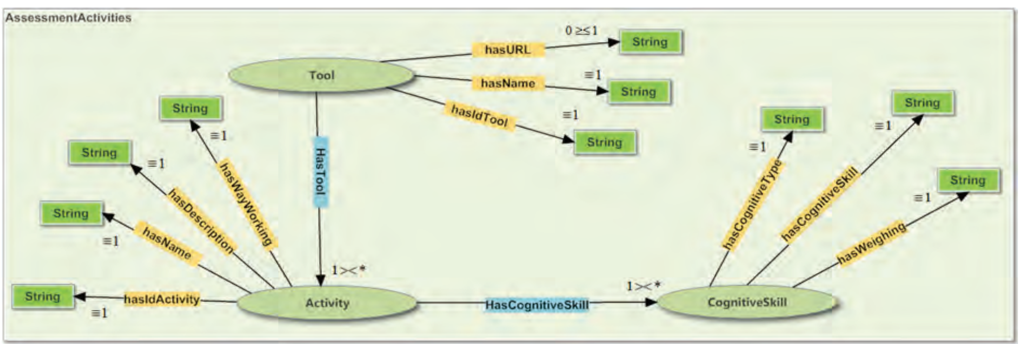

Figure 5. Assessment Actvities Ontology

Finally, we propose to systematize the experiment through an ontological model design that allows to generalized the personalization of learning activities in different courses.

6.2. Results

The results of the test applied to the students in each trimester in a structured programming (SP) course or in a numerical methods in engineering (NME) course are shown in figure 6 and 7 respectively. It can be observed that there was an increase in all the average rating in all thinking styles.

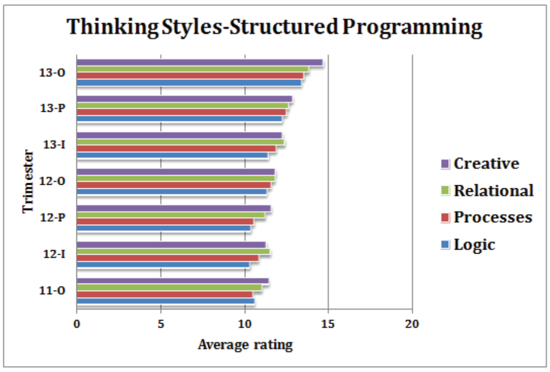

Figure 6. Average rating in the thinking style of SP-course.

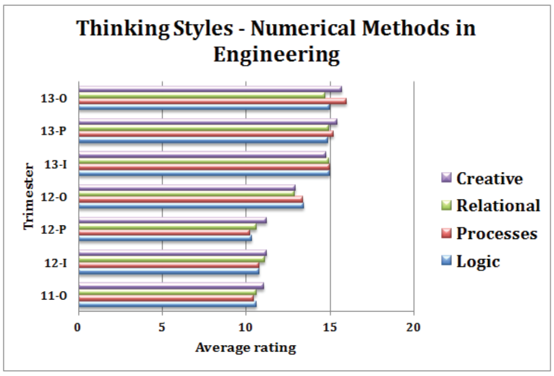

Figure 7. Average rating in the thinking style of NME-course.

The figure 8 shows the assessment activities in structured programming course in SAKAI portal. The activities are selected according with the learning profile. SAKAI [22] is Learning Management System (LMS) open source where were implemented both courses.

7. Conclusions

The personalization of the assessment activities is a complex task, that involves three variables: the student's thinking style, course objectives and units objectives, as well as the evaluation technique. However, through the ontology set the personalization of assessments activities encourages educational innovation, invites to invent, to reconstruct at each stage the educational practices and to attend student needs, keeping in mind that everything is immersed in a very specific context and that changes must be adapted to this context. These interventions allow the student to have better opportunities for intellectual and moral development, as established by Piaget [23] and Vygotsky [24,25].

The personalization of the learning path: 1) allows students to develop the desired competencies as part of the course objectives, 2) it is a mechanism of self-motivation, when the student feels that he/she is treated differently his/her attitude changes throughout the course.

The proposed ontological model potency the assessment as a mechanism not only for change, but also for strategic learning. Assessment becomes the main engine of a new learning culture, enabling them to continue learning throughout life.

The results of fieldwork provide encouraging results presented in figures 6 y 7. The student dominance average was increased more in the logic and creative styles.

This developed ontologies involve teaching reengineering, whose success depends on the paradigm change, in the professional work of teachers, since they are the principal assistants in student learning. Innovation, creativity, invention, to search for alternatives is the new work of every teacher immersed in education mediated by new information and communication technologies.

8. Acknowledgements

We would like to acknowledge the support by the Department of Systems, Universidad Autónoma Metropolitana Azcapotzalco.

9. References

[1] G. Jiménez, L. Vega, J. Bernal. La reprobación escolar como objeto de estudio de la investigación educativa. Primer Congreso Latinoamericano de Ciencias de la Educación. 2010.

[2] P. Fermoso. La personalización, la socialización y la moralización como partes del proceso educativo. http://www.cholonautas.edu.pe/modulo/upload/Fermoso%20cap%209.pdf

[3] World Wide Web Consortium (W3C). OWL Web Ontolology Language Guide. (Eds). Smith, M., Welty, C., McGuinness, D, 2009. http://www.w3.org/TR/owl-guide/

[4] Protégé 3.0. http://protege.stanford.edu/

[5] O. Apud. Evaluar para la transformación. Argentina, Paidos (Tramas. Sociales), 2000.

[6] A. L. Brown. The development of memory: Knowing, knowing about knowing, and knowing

how to know. In: H. W. Reese (Ed.), Advances in child development and behavior. New York: Academic Press, 1975.

[7] C.B. Chadwick. Estrategias cognitivas y afectivas de aprendizaje. Revista Latinoamericana de Psicología, 1-32, 1988.

[8] J. H. Flavell. Cognitive monitoring. In W.P. Dickson (Ed.), Children's oral communication skills. New York: Academic Press, 1981.

[9] P. MacLean. Education and the brain. Chicago: Chicago Press, 1978.

[10] R. Sperry. Lateral specialization of cerebral function in the surgically separated hemispheres. In: F. J. McGuigan (Ed.). The Psychophisioly of the thinking. New York: Academic Press, 1973.

[11] M. Herrmann. The creative brain. Búfalo: Brain books, 1989.

[12] W.L. VerLee. Aprender con todo el cerebro. Barcelona (España): MartínezRoca, 1986.

[13] J. Gómez. Neurociencia Cognitiva y Educación. Fondo Editorial FACHSE. Serie: Materiales del Postgrado. Ciudad Universitaria de Lambayeque, Perú, 2004.

[14] Hayashi Y., Bourdeau J., Mizoguchi R. Using Ontological Engineering to Organize. Learning/Instructional Theories and Build a Theory-Aware Authoring System. International Journal of Artificial Intelligence in Education 19, pages 211-252, 2009.

[15] Silva-López, R., Méndez-Gurrola, I., Sánchez-Arias, V. Strategic learning, towards a teaching reengineering. Research in computing science. 65, pages 133-145, 2013.

[16] N. Guarino. Formal Ontology, Concept Analysis and Knowledge Representation. International Journal of Human and Computer Studies. 43 (5/6): 625-640, 1995.

[17] N. Guarino. Formal Ontologies and Information Systems, en N. Guarino (ed.): 3-15, 1998.

[18] L. D. McGuinness. Ontologies Come of Age. In Dieter Fensel, Jim Hendler, Henry Lieberman, and Wolfgang Wahlster, editors. The Semantic Web: Why, What, and How, MIT Press, 2003.

[19] T. R. Gruber. A Translation Approach to Portable Ontology Specifications. Knowledge Acquisition, 5(2), 199-220, 1993.

[20] N. F. Noy, D.L. McGuinness. Ontology Development 101: A Guide to Creating Your First Ontology. Stanford Knowledge Systems Laboratory Technical Report KSL-01-05 and Stanford Medical Informatics Technical Report SMI-2001-0880. 2001.

[21] Silva-López, R., Sánchez-Arias, V. Méndez-Gurrola, I. Ontological model to represent the student's learning profile. In proceedings of the 6th International Conference of Education, Research and Inovation, 2013.

[22] Sakai, http://www.sakaiproject.org/

[23] L. Piaget. Sociological studies (I. Smith, Trans. 2nd ed.). New York: Routledge. Top, 1995.

[24] L. Vigotsky. El significado histórico de la crisis en psicología. Una investigación metodológica. Obras Escogidas, T. I. Madrid. Visor, 1993.

[25] L. Vigotsky. Historia del desarrollo de las funciones psíquicas superiores. En Obras Escogidas, T. III, Madrid. Visor, 1995.

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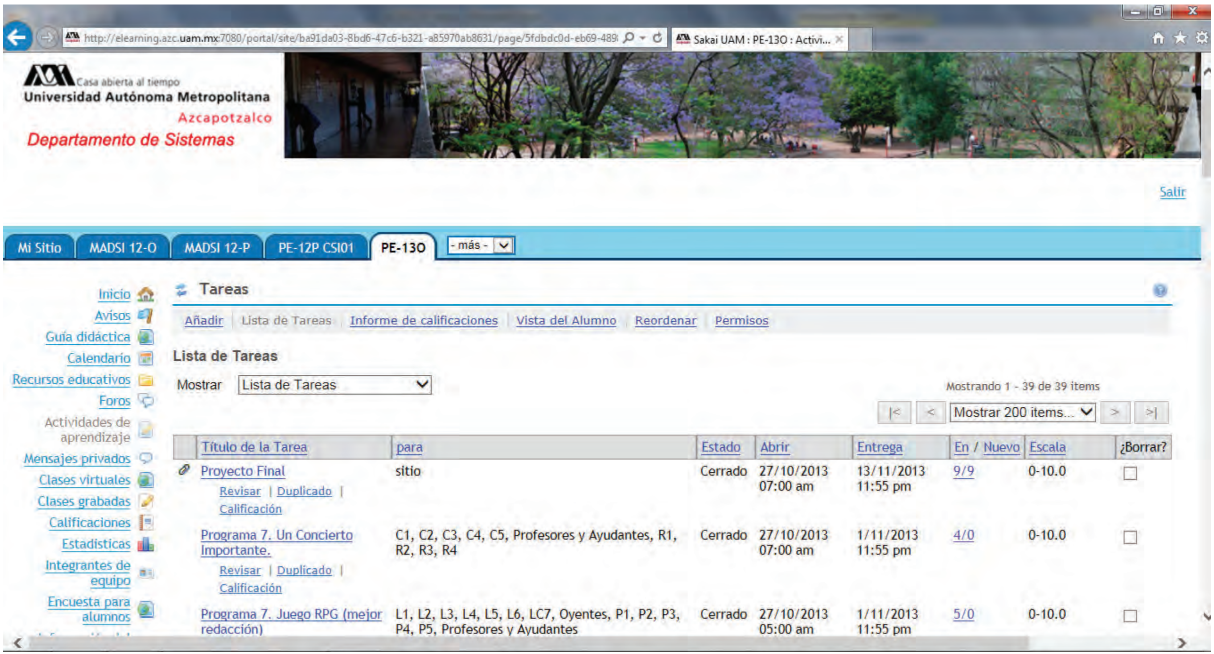

Figure 8. SAKAI platform with assessment activities

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Approach to Seismic Signal Discrimination based on Takagi-Sugeno Fuzzy Inference System

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Abstract
The aim of the present study is to investigate and explore the potential of Takagi–Sugeno fuzzy inference system for seismic signal discrimination between quarry blast and earthquake events. Such fuzzy system can be an appropriate classification platform due to its robustness to incorporate imprecise knowledge and its capability of integrating different information as the one coming from expert knowledge and the information coming from mathematical expressions. Relevant seismogram characteristics are extracted from seismic signal based on time and frequency domains. Using these characteristics, a fuzzy classifier was built based on analyst experience. Classification result using real seismic data reveals that the classifier performance can achieve 100%.

***Keywords**: Seismic discrimination, Seismic signal processing, Feature extraction, Takagi-Sugeno fuzzy inference.*

1. Introduction
A challenge and essential task in seismic monitoring systems is to automatically discriminate between natural seismicity and anthropogenic events such as quarry blasts. This is due to the complexity of seismic signal on one hand, and on the other hand, the very high volume of data recorded continuously. Owing to the central role of such task, a variety of waveform based discrimination methods have been developed and investigated. These methods include spectral ratio of seismic phases or average amplitude in low and high frequency bands for a specific phase (Hedlin et al., 1990 [1]; Gitterman and Shapira, 1993 [2]; Gitterman et al [3]., 1998; Koch and Fah, 2002 [4];Allmann et al., 2008 [5]; Dahy and Hassib, 2010 [6]), statistical analysis (Kushniret al., 1990 [7]; Wuster, 1993 [8]; Kushnir et al.,1999 [9]), cross-correlation techniques (Harris, 1991[10]), and Wavelet Bayesian classification (Gendron et al., 2000 [11]). Other approaches use Neural network techniques (e.g., Falsaperla et al., 1996 [12]; Musil and Plesinger, 1996 [13]; Muller et al., 1999 [14]; Dowla et al., 1990 [15]; Tiira, 1999 [16]; Jenkins and Sereno, 2001[17]; Ursino et al., 2001[18]; Del Pezzo et al., 2003[19]; Scarpetta et al., 2005 [20]; Yıldırım et al, 2010 [21]).
This study is concerned with the application of Takagi–Sugeno fuzzy system (Takagi and Sugeno, 1985 [22]) to the problem of seismic discrimination between earthquake and quarry blast events. The research area in this work is Agadir city and its vicinity, which is situated in Morocco. For the purpose of identification of different active tectonics and analysis of seismicity of the region, a local seismic network was founded in 2001. The seismic network consists of five stations vertical-component short-period seismometer with an output proportional to ground velocity. The five stations are deployed around Agadir city and linked with Agadir's regional seismic database via a radio-frequency (RF) FM modulated, and with national database in Rabat via terrestrial phone line (Figure 1). Seismic data are continuously recorded and transmitted in real-time to the Agaidr's data center, where they are digitized and processed. Each stored event record should include a portion of seismic noise signal prior to detection time and a fixed recording time after detrigger time in order to assure complete recording of seismic events. The detection is performed by a power detector whereby the power over a short time-window (the short-term average, STA) is compared with the power over a long time-window (the long-term average, LTA) [23]. The basic idea of the algorithm is that an event is considered detected when the STA/LTA ratio exceeds a pre-determined threshold. Due to various quarrying activities in the vicinity of the region, many explosions are detonated and recorded by the seismic network every day. Such anthropogenic events contaminate the recorded natural seismicity of the region and lead to misinterpretation of the results. Therefore, an automatic task to discriminate quarry blasts seismograms from earthquakes ones in the seismicity catalog is crucial.

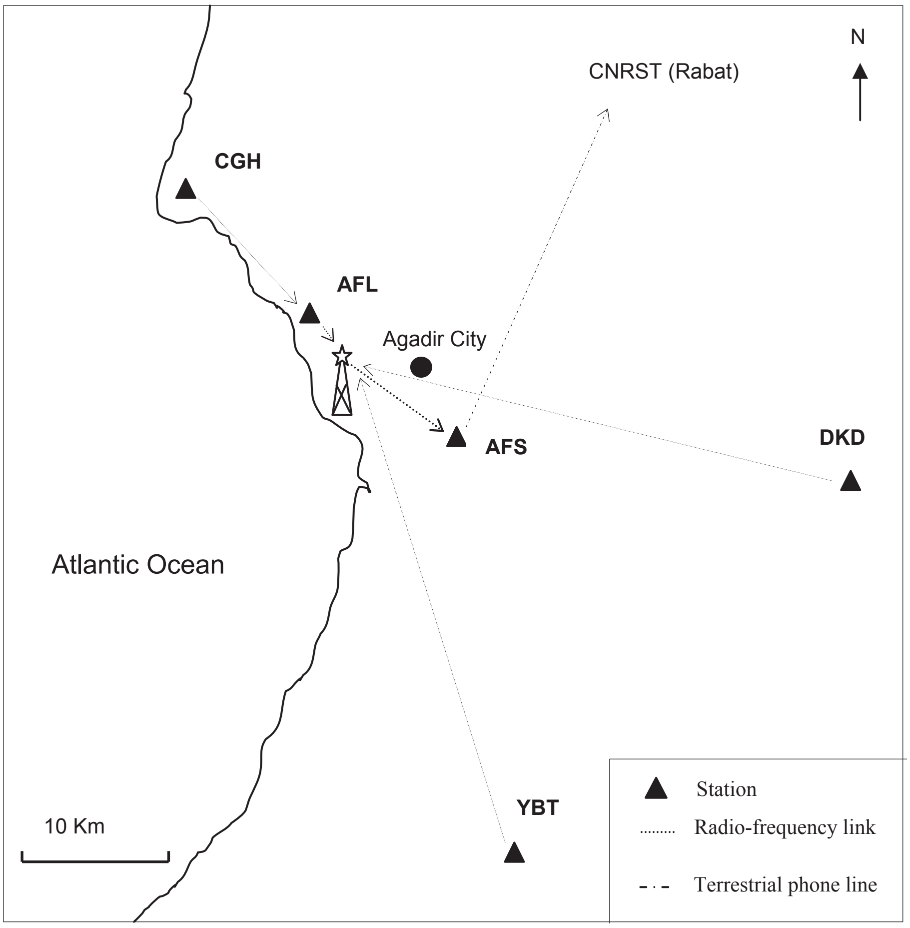

Figure 1. Stations location map of the local seismic network of Agadir

The driving force behind this work was to develop a reliable and automatic task that is able to mimic the analysts reasoning in discriminating between seismic events, and hence automatically identify earthquake events (*EQ*) from quarry blast ones (*QB*) which recorded by the local seismic network of Agadir. We addressed the problem by using fuzzy logic approach for several reasons, among which are the capability of modelling human reasoning and decision-making, the possibility of incorporating different information as the one coming from expert knowledge and information coming from mathematical expressions as well as its robustness to deal with imprecise knowledge. Such properties make a fuzzy classifier an appropriate platform to integrate the noisy and imprecise or incomplete information extracted from the seismic signal and the analyst experience knowledge. This combination will provide a good generalization performance.

The remainder of the paper is structured as follows. The second section discusses seismogram characteristics and parameters used for features extraction. The third section describes and explains the functioning of the fuzzy classifier developed in this study. The fourth section presents results of application of the proposed fuzzy classifier to real seismic data. Finally, the fifth section reports some significant conclusions of this study.

2. Data and feature extraction

The proposed seismic signal classification method in this study operates in two steps. The first step is seismogram feature extraction, where a set of scalar values representing significant seismogram features is extracted. The second step is seismogram classification, where the classifier uses the previous extracted features to classify seismic events. It is obvious that the performance of the classifier is affected by the feature set used. The feature parameters are usually selected based on expertise and experience of the seismic signal analyst. In this section we present some seismograms of quarry blast events recorded by the seismic local network of Agadir, together with earthquake seismograms for comparison study between these two events. Such study is useful to highlight some discriminant characteristics between the signals generated by the two types of events. Figure 2 depicts the vertical component seismogram of two earthquakes (a, b) and two quarry blasts (c, d).

2.1 Seismogram characteristics

The simplest classification method used to discriminate between earthquakes and quarry blasts is based on the hour of event detection [24]. This method relies on the fact that quarry blasts are detonated during working hours. Therefore, hourly, daily and weekly distribution of earthquakes and quarry blasts can be analysed and used for discrimination. Such statistical method is insuf-

ficient because it cannot separate between the quarry

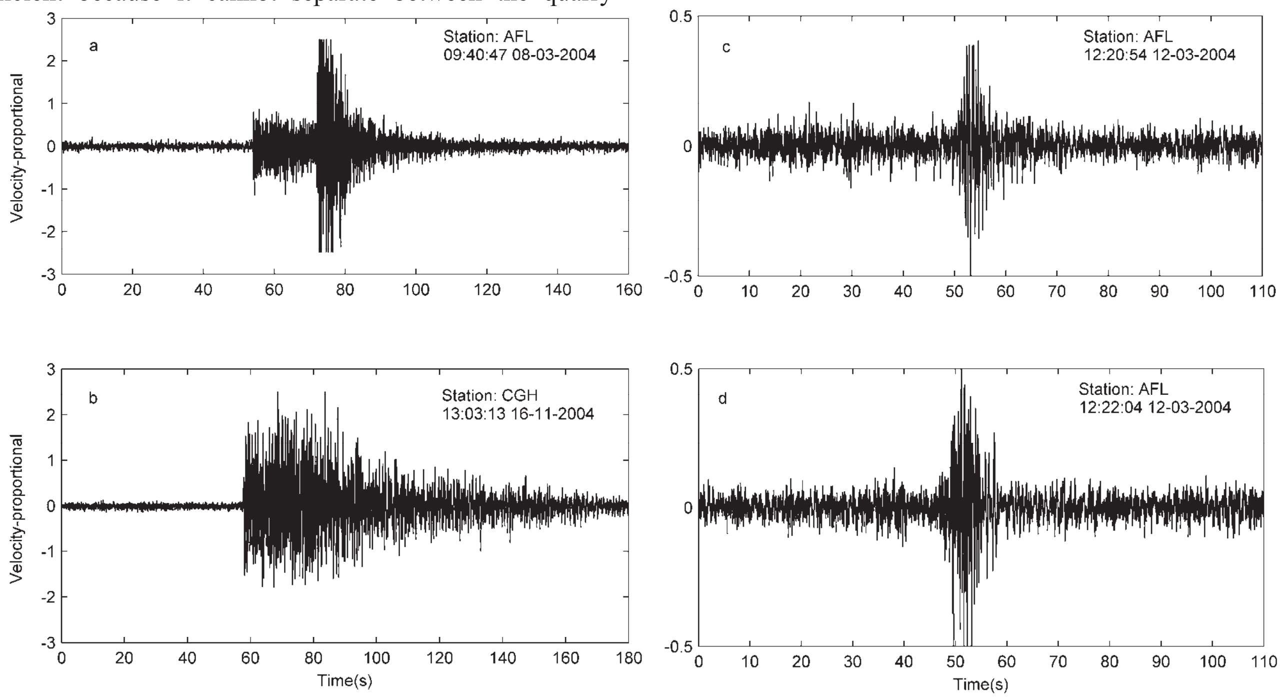

Figure 2. Vertical component seismogram of two earthquakes (a, b) and two quarry blasts (c, d) recorded by the local seismic network of Agadir.

blast and earthquake events recoded during working hours, but it can be used with other methods for result verification.

In order to extract other discriminant parameters, the waveforms of these events must be investigated. Due to different source characteristics of each event, it is expected that the waveform and spectrum characteristics of these two events will be also different. In fact, an earthquake source is much more complicated phenomenon than explosion one. The spatial as well as the temporal dimension of an earthquake is larger than those of an explosion of comparable strength. Additionally, an explosion is almost truly symmetric, sending out seismic waves of approximately the same strength in all directions. Whereas most of earthquake sources are highly asymmetric, sending out different seismic signals in different directions. These different sources properties introduce diverse characteristics to the seismic signal that may be readily used to identify each type of source and discriminate between explosions and tectonic earthquakes. The quarry blast waveform is dominated by the P-wave (the first arrival), whereas the earthquake has a much larger S-wave and surface waves.

In a preliminary look at figure 2, it seems that signal envelope is a promising discrimination parameter. The quarry blasts records are characterized by overlapped P and S waves, less impulsive onset and short duration of coda waves. These characteristics blend together to form a Gaussian envelope.

It is evident that dislocation sources such as earthquakes generate more shear-wave (S-wave) energy than explosion sources. As it can be seen in the figure 2, signal associated with an earthquake differs appreciably from that of an explosion in that it involves large S waves, isolated or overlapped P and S waves (it depends on source-station distance) and exponential decay of coda amplitude with time.

Analysis of many explosion signals shows that all the events have almost the same envelope, and can be recognized using only the envelope. Unfortunately, not only the explosion signals that show this feature; some earthquake signals have also the same envelope as explosion. In order to find another parameter which can differentiate these types of event, we analysed their signals in the frequency domain. Figure 4 displays seismograms of an earthquake and a quarry blast with their associated FFT. Comparison between the two seismograms reveals that envelopes of these two events are quite similar, whereas the difference between their spectral content is clearly visible. It was observed that seismograms of quarry blast exhibit very low frequency amplitude below 1Hz. Contrary to earthquake seismograms, which often show very high frequency amplitude in the same band.

Another important parameter to be considered in this study is time duration of the event. Time duration is influenced by many factors, mainly the characteristic dimensions of the source. Thus, it should be expected that time duration of natural earthquakes would be longer than the time duration of explosions. Examination of many events displays that explosion records have durations of less than 40 seconds while tectonic earthquake records may last for several minutes.

2.2 Feature extraction

The discriminant features discussed above can be mathematically formulated as the following:

Envelope E: To extract the signal envelope, we use the Hilbert Transform *HT* which is capable of tracking the amplitude envelope of the signal (figure 3):

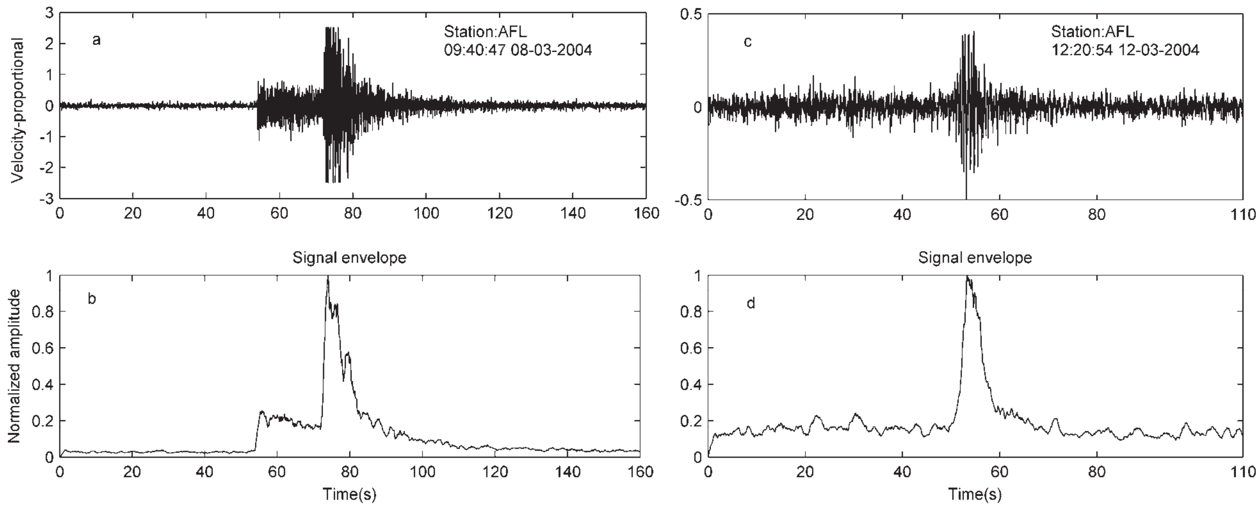

Figure 3. Seismograms of an earthquake (a) and a quarry blast (c) and their corresponding envelope (b) and (d)

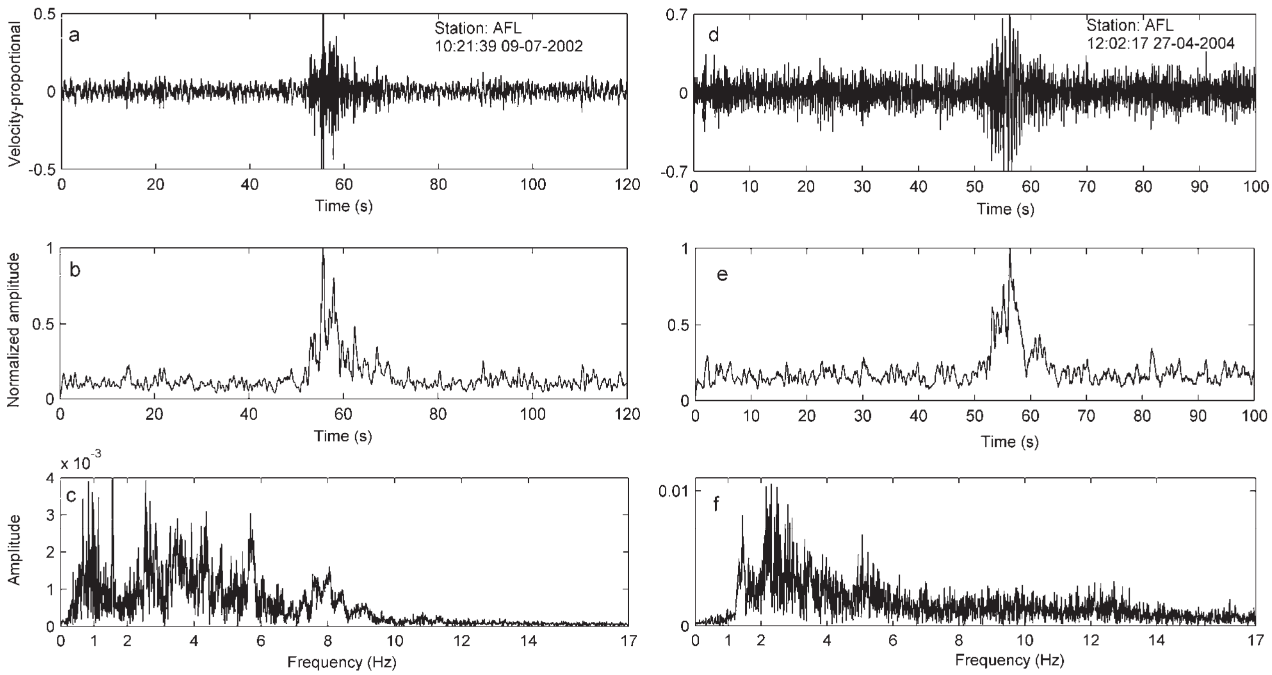

Figure 4. Comparison between seismogram of an earthquake (a) and a quarry blast (d) and their corresponding envelope (b, e) and FFT (c, f)

$$HT[x(t)] = x(t) * \frac{1}{\pi t}$$

$$= \frac{1}{\pi}\left[\int_{-\infty}^{+\infty} x(t).\frac{1}{(t-\tau)}.d\tau\right]$$

From the given signal *x(t)*, a complex signal *A[x(t)]* (also known as analytical signal) that is associated with the original signal can be constructed as :

$$A[x(t)] = x(t) + jHT[x(t)]$$

The envelope of the signal is then defined as:

$$E = \sqrt{x(t)^2 + HT[x(t)]^2}$$

A finite impulse response filter (*FIR*) is designed to minimize the rapid variation of the envelope. As quarry blast signals usually display the same shape, we have chosen a quarry blast envelope to be a template envelope, which will be compared with the envelope of each upcoming event.

***Time duration T_d*:** T_d is defined as the total duration in seconds of the event record from the P wave onset t_p to the end of the signal t_{end}. The latter is defined as the point where the signal is no longer seen above the noise.

$$T_d = t_{end} - t_p$$

Hour H: *H* is the hour of event detection. Quarry blast events occur during the time day from 11:00 a.m. to 02:00 p.m. and from 05:00 p.m. to 06:00 p.m. Beyond this time intervals, the explosion are absent, and hence the seismicity pattern is not affected by anthropogenic events. *H* can be expressed as the following:

H = hour+minute/60+second/3600

***Frequency content E_s*:** The frequency amplitude of each seismic event signal is calculated in the frequency band [f1 f2] = [0.5 1]*Hz* by the following equation:

$$E_S = \int_{f_1}^{f_2} a(f)df$$

As this parameter can be significantly altered by noise, an adaptive filter has been designed to subtract the noise *FFT* from the event one. The noise *FFT* is computed using the pre-event noise signal. A typical example of this process is illustrated in figure (5)

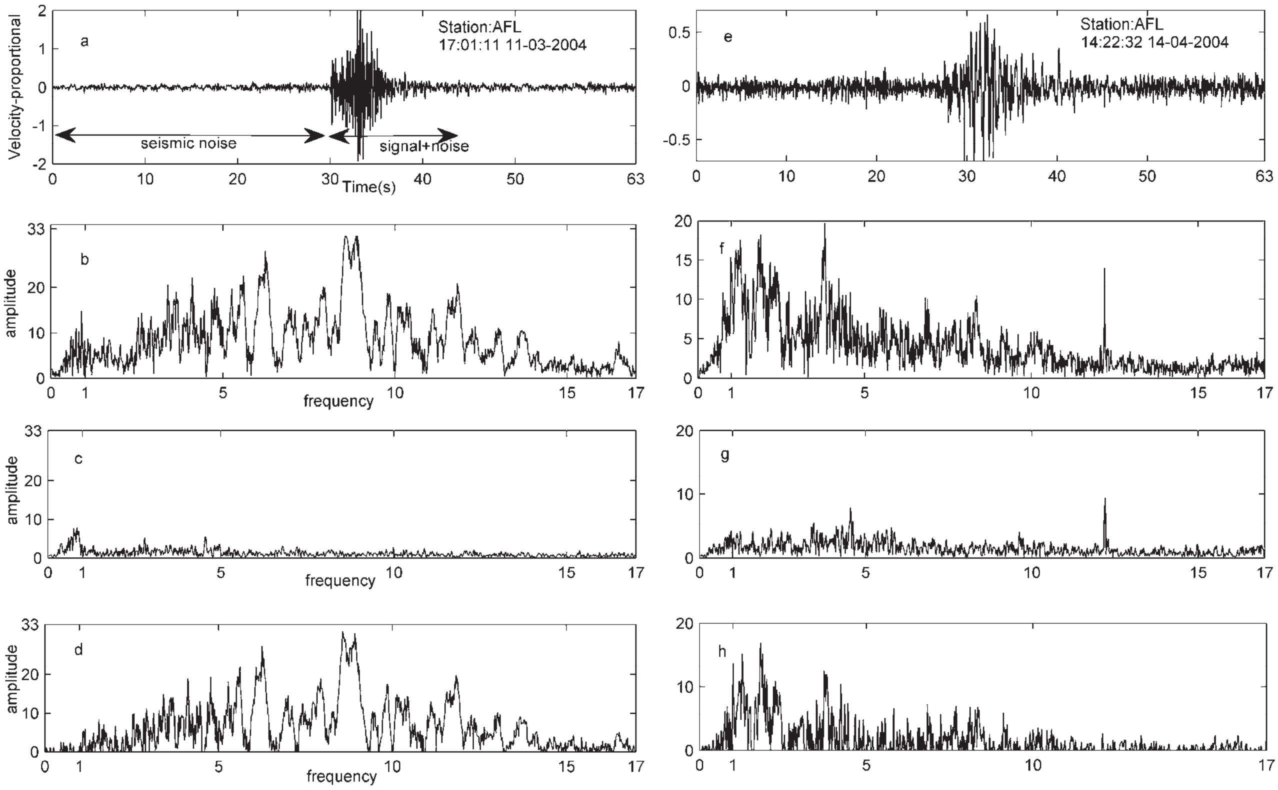

Figure 5. Exemples of denoising results for two seismic events. (a, e) the noisy seismograms, and their FFT (b, f). (c, g) FFT of the pre-event noise signal. (d, h) FFT of the denoised seismograms.

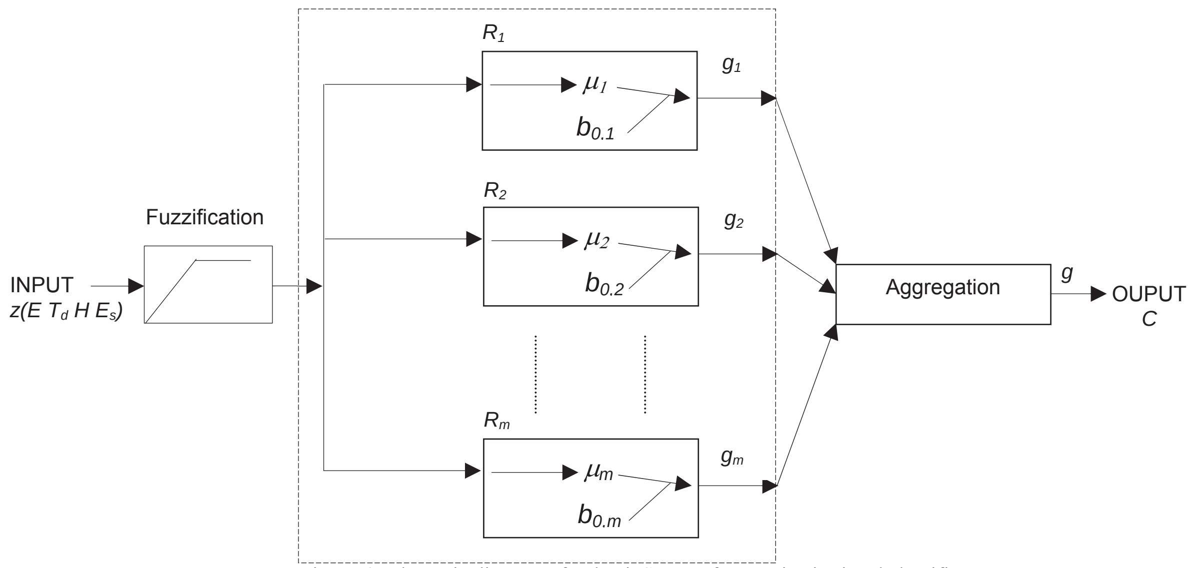

Figure 6. schematic diagram of Takagi–Sugeno fuzzy seismic signal classifier

3. Fuzzy classifier

Fussy logic systems try to mimic the way humans interpret and reason with real-world knowledge in the face of uncertainty. It is founded on fuzzy set theory (proposed by Zadeh, 1965). The latter is a generalization of classical concept of set, in which membership is defined as a question of degree rather than in a binary manner. Thus, the transition from a fuzzy set to its neighbors is gradual rather than abrupt, resulting in continuity and robustness. This gradual change is expressed by a membership function μ valued in the real unit interval [0, 1]. This theory provides an approximate and yet effective means for describing the characteristics of a system that is too complex to admit precise mathematical analysis. Generally speaking, fuzzy logic provides the appropriate tool to manipulate the real-world data, where information is often incomplete and does not have sharply defined boundaries.

A fuzzy system implements a nonlinear mapping from its input space to output space. The process that describes the input-output relation of a real system using fuzzy logic is called the fuzzy inference. Fuzzy inference systems are non-linear models that consist of three conceptual components: a rule base, which contains a selection of fuzzy rules; a database, which defines the membership functions used in the fuzzy rules; and a reasoning mechanism, which performs the inference procedure upon the rules and given facts to drive a reasonable output or conclusion. A typical fuzzy rule in fuzzy system has the following form:

R_i: IF (x_1 is A_{i1}) AND (x_2 is A_{i2}) AND…..AND (x_n is A_{in}) THAN y_i is …

R_i indicates the ith rule (if the number of rules in the system is m then $i=1,2,\ldots,m$); x_k; $k=1,\ldots,n$ is the input vector, and y_i is the rule consequent. The terms A_{ik} represent antecedent fuzzy sets of ith rule used to partition the input space into overlapping regions. Each fuzzy set A_{ik} is described by its membership function μ_{ik}, which evaluates the degree to which each input variable x_k belongs to the fuzzy set A_{ik} through the corresponding membership value $\mu_{ik}(x_k)$. The membership values $\mu_{ik}(x_k)$vary in the range [0, 1]. The structure of the rule consequents depends on the type of fuzzy inference system under consideration. In this work the Takagi–Sugeno fuzzy system is employed. In this case, the consequents of the rules are functions of the input variables:

$Y_i=f_i(x_1,x_2,\ldots x_n)$

The functions f_i are usually first order polynomials, given by:

$f_i(x_1,x_2,\ldots x_n)= b_{0,i}+b_{1,i}x_1+ b_{2,i}x_2,\ldots, b_{n,i}x_n$

Functioning of Takagi–Sugeno fuzzy system as a seismic classifier

Let $C=(EQ, QB)$ indicate the two classes of seismic events, which can be described by a set of features or attributes ($E\ T_d\ H\ E_s$), i.e., a given event z to classify is an element $x=(e ,t_d ,h,e_s)$ of $X_i=(E \times T_d\times H\times E_s)$, where x_i is the value taken by attribute i for this event. In the sequel, X_i will indicate either the attribute (i.e., variable) itself or its set of values, while x_i indicate possible values of X_i. The problem of designing the classifier is to define a mapping F such as:

$F: E \times T_d\times H\times E_s \rightarrow C$

Our classifier is a zero-order Sugeno fuzzy system, in which f_i is a constant:

$f_i\ (e ,t_d,h,e_s)= b_{0,i}$

Therefore, R_i can be rewritten as the following:

R_i: IF (e is A_{i1}) AND (t_d is A_{i2}) AND (h is A_{in}) AND (e_s is A_{in}) THAN $y_i=b_{0,i}$

$$b_{0,i}=\begin{cases} c_1 & \text{for EQ} \\ c_2 & \text{for QB}\end{cases}$$

Fig. 6 shows a schematic diagram of the functioning of our Sugeno fuzzy fuzzy classifier. The classification of a given seismic event $z(e, t_d, h, e_s)$ involves the following steps:

- Fuzzifying the input
- Calculation of the degree of fulfilment μ_i of each rule. The degree of fulfilment of a rule evaluates the compatibility of a given input vector with the antecedent of the rule (i.e. the IF part). The degree of fulfilment is normally evaluated using a t-norm, such as the algebraic product:
-

$$\mu_i(z)=\mu_{i1}(e).\mu_{i2}(t_d).\mu_{i3}(h).\mu_{i4}(e_s)$$

- Calculation of the output g_i of each rule:

$$g_i(z)=\mu_i(z).y_i$$

- Obtaining of the final system output g as the weighted average of the outputs of the rules.

$$g(z)=\sum_{i=1}^{m}\frac{g_i(z)}{\sum_{i=1}^{m}\mu_i(z)}$$

4. Results and discussion

In this section we implement, tune and test the performance of the classifier. As previously described in section 3, the classifier is a mapping of four inputs described by four parameters ($E\ T_d\ H\ E_s$) to an output C, indicating the class (EQ, QB) to which the input belongs. Discriminative parameters are illustrated in table 1, where their corresponding fundamental descriptive statistical information for each class is provided. Such information is useful in defining the membership functions. To represent the variable Hour, the histogram was used (fig. 7).

Table 1. Discriminative parameters and their corresponding fundamental descriptive statistical information for the two classes EQ and QB.

	T_d		E		E_s	
	EQ	QB	EQ	QB	EQ	QB
min	013.69	09.06	0.47	0.09	0.08	0.22
max	736.80	32.03	0.98	0.55	190.12	7.44
mean	135.39	17.30	0.82	0.39	20.51	2.38
std	150.45	04.83	0.12	0.09	39.51	1.58

The statistical data show that each variable presents overlapping ranges within the two classes. Therefore using one variable alone cannot separate between the two classes. The most accepted solution for discrimination is the combination of all these different parameters in one system so that each overlapped region by one parameter can be separated by the others. At this point, the fuzzy inference system plays an important role.

The first step in fuzzy systems is the fuzzification stage, which is characterized here by eleven membership functions: ‘night’, ‘morning’, ‘noon’, ‘afternoon’, ‘evening’ for the variable Hour H, ‘short’ and ‘long’ for the variable duration T_d, ‘Guassian’ and ‘non-Guassian’ for the variable envelop E, ‘low’ and ‘high’ for the variable frequency content E_s, and ‘earthquake’, ‘quarry blast’ for the variable class C. The membership functions that were adopted in this paper have trapezoidal forms except for those of the variable class which are singletons. Based on the analyst knowledge and the above fuzzy descriptions of each variable, we have implemented the seismic classification system using a set of fuzzy rules.

In order to evaluate the classification accuracy of the system, we have used a data set that consists of 120 events, composed of 60 events for the class EQ and 60 events for the class QB. A comparative study of each discriminant parameter values for the two classes is displayed in figure (8).

In order to assess the influence of integrating several parameters on the classifier performance, we compute the percentage of correct classification using the same data in the case of employing only two variables ($E\ H$) as input to the classifier, three variables ($E\ H\ T_d$ or $E\ H\ E_s$) and finally four of them. The classification results are presented in table 2.

Table 2. Classification results

parameters	$E\ T_d\ H\ E_s$	$E\ T_d\ H$	$E\ H\ E_s$	$E\ H$
Results (%)	100	100	97.5	97.5

The classification result reveals that using only envelop and hour parameters without duration and frequency content, the classier reaches a performance of 97.5%. This means that the combination of the input related to the signal envelop and the input related to the hour of detection provide the classifier with the most information needed to discriminate between the two classes. Such performance can never be achieved when only one parameter is used. In this case, the classifier makes its decision based on the two variables so that events that fail one variable may success the other.

The addition of the parameter duration increases the performance of the classifier to 100%. From this result it turns out that the classifier reaches the maximum performance based only on the three parameters ($E\ T_d\ H$) and hence the parameter frequency content (E_s) has no effect on the classifier performance. Nevertheless, we still keep such parameter because it may be very efficient in the situations where earthquake events with the same envelop as quarry blast events occur in the time range where quarry blast are exploded.

Besides the greater flexibility that fuzzy systems offer due to the fuzzy instead of crisp classification thresholds, here is another important property of fuzzy systems which enables constructing an input-output mapping based on not only the available data set but also the expert knowledge. This will lead to expand the generalization capabilities of the classifier.

The combination of several features in one system allows us to exploit the information provided by each one and hence separate overlapped region and get an automatic discrimination system reaching the maximum performance. Furthermore, using a fuzzy logic classifier enables us to take advantage of its flexibility, ability to cope with different types of inputs and its decision making structure. In fact fuzzy classifiers have to make decisions based on many different variables and expert knowledge;

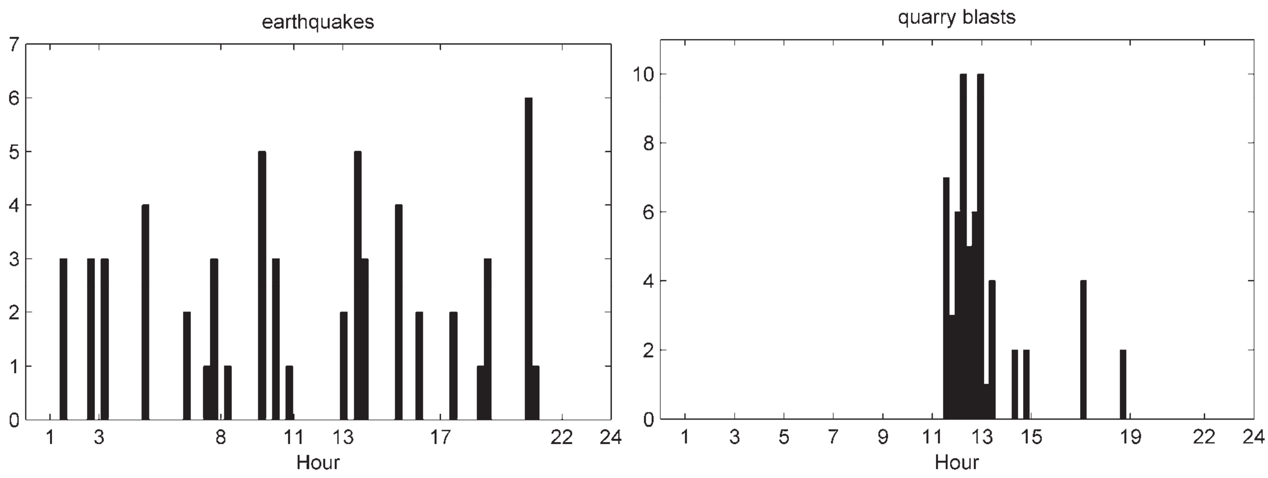

Figure 7. Histogram of the parameter Hour for both earthquake and quarry blast classes.

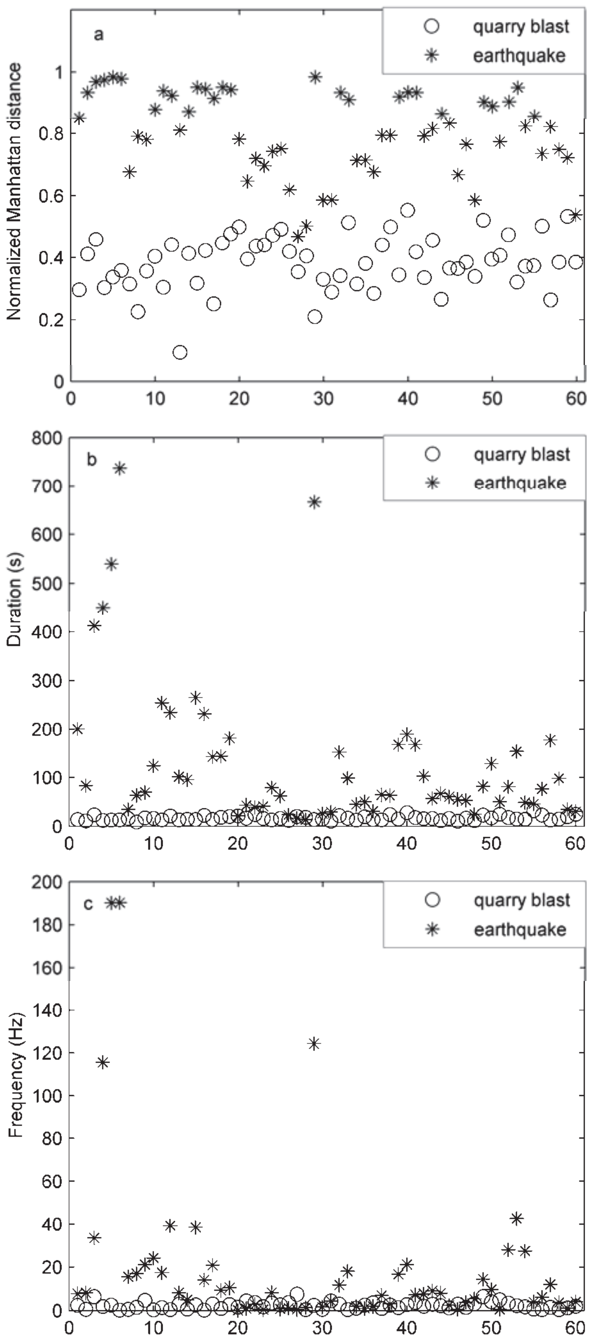

Figure 8. Discriminant parameters values compared for 60 quarry blast and earthquake events. (a) envelop, (b) duration and (c) frequency content

thus, offering much more capability and possibility than the classical statistical systems as well as data training based methods which suffer from significant performance degradation when the available training data are insufficient.

The results of this research have shown that the fuzzy approach is perfectly suitable for distinguishing earthquake events from quarry blast ones. Such technique, achieved a high discrimination performance with low complexity, could be employed in online discrimination. Moreover, by using fuzzy logic rules, the maintenance of the classifier is straightforward. The features characteristics of each class might change in the future, but the underlying fuzzy classifier will be the same. For example, the quarry blasts exploding time can be changed in the future but, the system can be recalibrated quickly by simply shifting the fuzzy set that defines Hour or just rewriting the fuzzy rules without touching the complex programming code. Also, adding more rules to the bottom of the list to increment or expand the scope of the knowledge-base, as processes develop or new events are found, is relatively easy and without needing to undo what had already been done. In other words, the subsequent modification was pretty easy. The last statement is perhaps the most important one and deserves to be addressed here. Since fuzzy logic is built on top of linguistic terms used by ordinary people on a daily basis, fuzzy logic allows anyone to edit and modify the rules without worrying about underlying code.

5. Conclusion

In this paper, an automatic discrimination method between earthquake and quarry blast events in Agadir's seismic database is developed using Takagi-Sugeno fuzzy inference system. Each event is represented by a set of features deduced from the corresponding signal. The fuzzy system interprets the values in the input vector and, based on a set of fuzzy rules, assigns each input to its class. Fuzzy logic is used here as another tool worth considering when implementing nonlinear problems and treating uncertain and imprecise data, but otherwise fuzzy logic should be considered in view of its simplicity and transparency. This simplicity however does not limit its effectiveness.

The classification results show that fuzzy classifier appear to be a powerful tool to deal with seismic signal, which is distorted, weakly, noisy and complex. Furthermore, since fuzzy logic is very useful in acquiring knowledge from human experts, it is very suitable for situation where training data are insufficient. In addition, Fuzzy classes reflect reality better and allow decision makers to describe input attributes and output classes more intuitively using linguistic variables, overlapping classes and approximate reasoning. Events that belong to more than one class are treated in all classes where they have partial membership.

The achieved results validate the good performance with low complexity of the fuzzy classifier and demonstrate the appropriateness of fuzzy logic to incorporate and exploit the information obtained from many parameters. This approach shows that the classification results can always be improved by adding other relevant features.

6. References

[1] M. Hedlin, J.B. Minster, J.A. Orcutt. An automatic means to discriminate between earthquakes and quarry blasts. Bull. Seism. Soc. Am. 80, 2143–2160, 1990.

[2] Y. Gitterman and A. Shapira. Spectral discrimination of underwater explosions. Israel Journal of Earth Science 42, 37–44, 1993.

[3] Y. Gitterman, V. Pinky and A. Shapira. Spectral classification methods in monitoring small local events by the Israel seismic network. J. Seismology 2, 237–256, 1998.

[4] K. Koch and D. Fah. Identification of earthquakes and explosions using amplitude ratios: theVogtland area revisited. Pure and Applied Geophysics 159,735–757, 2002.

[5] P. B. Allmann, P. M. Shearer and E. Hauksson. Spectral discrimination between quarry blasts and earthquakes in Southern California. Bull. Seism. Soc. Am., Vol: 98, Issue: 4, Pages: 2073-2079, 2008.

[6] S.A. Dahy and G.H. Hassib. Spectral discrimination between quarry blasts and micro earthquakes in southern Egypt. Research Journal of Earth Sciences 2 (1), 1–7, 2010.

[7] Kushnir, A. F., V. M. Lapshin, V. I. Pinsky, and J. Fyen (1990). Statistically optimal event detection using small array data, Bull. Seism. Soc. Am. 80, 1934–1950.

[8] J. Wuster. Discrimination of chemical explosions and earthquakes in central Europe—a casestudy. Bull. Seism. Soc. Am. 83, 1184–121, 1993.

[9] A. F. Kushnir, E. V. Troitsky, L. M. Haikin, and A. Dainty. Statistical classification approach to discrimination between weak earthquakes and quarry blasts recorded by the Israel Seismic Network, Phys. Earth Planet. Int. 113, 161–182, 1999.

[10] D. B. Harris. A waveform correlation method for identifying quarry explosions. Bull. Seism. Soc. Am. 81, 2395–2418, 1991.

[11] Gendron, P., J. Ebel, and D. Manolakis (2000).Rapid joint detection and classification with wavelet bases via bayes Theorem, Bull. Seism. Soc. Am. 90, 764–774.

[12] S. Falsaperla, S. Graziani, G. Nunnari, S. Spampinato. Automatic classification of volcanic earthquakes by using multi-layered neural networks. Natural Hazards 13, 205–228, 1996.

[13] M. Musil and A. Plesinger. Discrimination between local micro earthquakes and quarry blasts by multi-layer perceptrons and Kohonen maps. Bull. Seism. Soc. Am. 86 (4), 1077–1090, 1996.

[14] S. Muller, P. Garda, J.D Muller and Y. Cansi. Seismic events discrimination by neuro-fuzzy catalogue features. Physics and Chemistry of the Earth 24 (3), 201–206, 1999.

[15] F.U. Dowla, S.R. Taylor and R.W Anderson. Seismic discrimination with artificial neural networks: preliminary results with regional spectral data. Bull. Seism. Soc. Am. 80, 1346–1373, 1990.

[16] T. Tiira. Detecting teleseismic events using artificial neural networks. Computers and Geosciences 25, 929–939, 1999.

[17] R.D. Jenkins and T.S. Sereno. Calibration of regional S/P amplitude-ratio discriminants. Pure and Applied Geophysics 158, 1279–1300, 2001.

[18] A. Ursino, H. Langer, L. Scarfı, G. Di Grazia and S. Gresta. Discrimination of quarry blasts from tectonic microearthquakes in the Hyblean Plateau (south- eastern Sicily). Annali di Geofisica 44, 703–722, 2001.

[19] E. Del Pezzo, A. Esposito, F. Giudicepietro, M. Marinaro, M. Martini, S. Scarpetta. Discrimination of earthquakes and underwater explosions using neural networks. Bull. Seism. Soc. Am. 93, 215–223, 2003.

[20] S. Scarpetta, F. Giudicepietro, E.C. Ezin, S. Petrosino, E. Del Pezzo, M. Martini, M. Marinaro. Automatic classification of seismic signals at Mt. Vesuvius volcano, Italy, using neural networks. Bull. Seism. Soc. Am. 95, 185–196, 2005.

[21] E. Yıldırım, A. Gulbag, G. Horasan and E. Dogan: Discrimination of quarry blasts and earthquakes in the vicinity of Istanbul using soft computing techniques. Computers & Geosciences, 01-09, 2010.

[22] T. Takagi, M. Sugeno. Fuzzy identification of systems and its application to modeling and control. IEEE Trans. Sys., Man, and Cybernetics SMC-15 (1), 116–132, 1985.

[23] E. Akhouayri, D. Agliz, M. Fadel, and A. Ait Ouahman. Automatic detection and indexation of seismic events. AMSE Periodicals, Advances in Modeling and Analysis, S. C, Vol. 56, 59-67, 2001.

[24] S. Wiemer, M. Baer. Mapping and removing quarry blast events from seismicity catalogs, short notes. Bull. Seism. Soc. Am. 90,525–530, 2000.

[25] Z. Kovacic, S. Bogdan: Fuzzy Controller Design -Theory and Applications. Taylor & Francis Group, LLC, Boca Raton, 2006.

[26] S. N. Sivanandam, S. Sumathi and S. N. Deepa: Introduction to Fuzzy Logic using MATLAB. Springer-Verlag Berlin Heidelberg , 2007.

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